EJECTION MITIGATION USING ADVANCED GLAZING: STATUS REPORT II

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EXECUTIVE SUMMARY

In response to the National Highway Traffic Safety Administration (NHTSA) Authorization Act of 1991 and ongoing research into rollover and ejection mitigation, NHTSA initiated a research program concerning occupant protection in motor vehicle rollover crashes. NHTSA is addressing this occupant protection issue from two perspectives–preventing a rollover from occurring and protecting vehicle occupants during a rollover, including reducing the likelihood of ejections. Almost 60 percent of rollover fatalities occur in the 10 percent of rollovers involving either complete or partial ejection of vehicle occupants. Occupant ejections occur either through structural failures, such as door openings, or through window openings. NHTSA is evaluating the potential of improved door latches, side head air bags, and advanced glazing systems (an automotive industry term for transparent openings) to reduce occupant ejection.

This report evaluates the progress of advanced glazing research since NHTSA issued its November 1995 report on occupant protection research to mitigate ejection through window openings. Each year on average about 7,300 people are killed and 7,800 people are seriously injured because of partial or complete ejection through glazing. Of the fatalities, more than 4,400 are associated with vehicle rollovers and the majority of these rollover victims were not using safety belts. In fact, 98 percent of occupants completely ejected and killed during rollover crashes were unbelted.

Advanced glazing systems could save between 500 and 1,300 lives per year. These estimates assume a national safety belt use rate of about 66 percent (the average between 1992 and 1996) and a 20 to 51 percent range of effectiveness for advanced glazing systems in preventing ejection. Higher safety belt use rates directly reduce the estimated benefits of advanced glazing systems. For example, a 71 percent safety belt use rate would reduce likely glazing benefits by 11 percent. An 81 percent use rate would reduce glazing benefits by 34 percent. As of the end of 1998, the U.S. national average seat belt use rate was 70 percent.

Four types of advanced glazings were evaluated: a non high penetration resistant (HPR) trilaminate, an HPR trilaminate, a bilaminate, and a polycarbonate (rigid plastic). Pilkington/Libbey-Owens-Ford assisted the agency in manufacturing prototype window system designs for the General Motors C/K Pickup side door. The original window encapsulation design was modified and encapsulated glazings were manufactured. Modifications were also made to the front door window frame to provide improved, occupant retention, while maintaining the window's ability to be operated. To date, this research has not yet evaluated the practicability or suitability of the proposed glazing systems in actual production vehicles. One known problem with the proposed designs is they are not applicable to vehicles with frameless side windows. The proposed door modifications either would require significant redesign or would not be applicable to these vehicles. Even for framed windows, some additional work is still needed to further examine the appropriate depth of the proposed U-channel design.

The previous status report had estimated incremental production costs of $48 per vehicle for front side windows if trilaminate glazing were used and $79 per vehicle for front side windows if rigid plastic were used. The projected leadtime estimated in the previous status report was about 3 years. These cost, weight, and leadtime estimates are only applicable to vehicles with framed windows. The designs tested in this report should have incremental costs similar to the previous estimates.

Three series of tests were performed on the advanced side glazing systems. First, NHTSA used an 18 kg (40 lb.) impactor to evaluate potential occupant retention capabilities. Second, the agency used an existing Federal Motor Vehicle Safety Standard 201 free-motion headform to evaluate the glazing systems' potential for causing head injuries. Third, the agency conducted HYGE sled tests with a full-sized dummy to evaluate the glazing systems' potential for causing head and neck injuries.

The results indicated that all but the non-HPR trilaminate had good potential for providing adequate occupant retention. Impacts into the advanced glazings produced similar potential for head injuries as impacts using the current, tempered glass side windows. The neck measurements from impacts into glazings were not repeatable, especially for impacts into tempered side glass. Despite this wide variability, impacts into tempered glass resulted in lower shear loads and moments than those into advanced glazings. In each case, the lowest neck injury measurements were from the tempered glass impacts.

Advanced glazing systems may yield significant safety benefits by reducing partial and complete ejections through side windows, particularly in rollover crashes. However, before NHTSA can determine conclusively the efficacy and safety of advanced glazing systems, more research is needed into both the practicability of the prototype systems and the risk of negative unintended consequences. Additional research should examine the likelihood of increased injuries to belted occupants, increased injuries due to partially opened windows, loss of visibility due to larger window frames, and entrapment due to more rigid side windows. Research must be conducted to finalize test procedures, such as selecting the appropriate impact speed, analyze necessary door modifications, and finalize performance criteria. Full vehicle testing should be conducted for rollover and side impact crash scenarios. Research must also evaluate the applicability of existing federal standards on glazing safety, including laceration, visibility, and durability, to the proposed advanced glazing systems. Additionally, advanced glazing systems should be evaluated as one component of comprehensive ejection prevention and mitigation strategies that include alternate or optional ejection countermeasures such as the recently introduced inflatable head protections systems.

1.0 INTRODUCTION

In November 1995, the NHTSA issued a report titled "Ejection Mitigation Using Advanced Glazings: A Status Report"[1]. That report documented research which established the problem size and potential benefits of preventing occupant ejection through the front side windows during automotive crashes. A prototype glazing system consisting of a modified door and glazing materials was designed and demonstrated. This glazing system was designed to use higher strength window materials to withstand the force of an occupant impact and to transfer impact forces from the glazing to the door and window frame of the vehicle. The prototype advanced glazing system was able to successfully retain an 18 kg (40 lb) mass impacting at 24 kmph (15 mph). This impact test was determined to be representative of the type, shape, and speed that could be expected during automotive crashes. The prototype glazing system was tested using a variety of window glazing materials, bilaminates, trilaminates, and polycarbonates (rigid plastics), to assess a wide range of performance characteristics. Additionally, the previous research used the FMVSS 201 free-motion headform[2] (FMH) to evaluate the potential for head injury to an occupant due to glazing impact. Preliminary testing with the FMH indicated a low potential for head injury from contacts with the prototype glazing system.

This report extends several aspects of the previous research. The benefits and cost effectiveness analyses are updated to include newer data and to address comments received in response to the previous report. A series of sled tests was conducted to evaluate any increased potential for neck injury by the use of advanced glazing systems. Additional testing was also conducted to evaluate the feasibility issues of using the retention and FMH impactor component tests.

1.1 Background

The previous advanced glazing systems were designed around the 1979-1980 Ford LTD driver side window. Due to the difficulty of acquiring older model vehicle components, a system from a more recent vehicle model year was needed. Development of these advanced door systems typically requires the use of custom molds for the glazing materials. In 1996, the Libbey-Owens-Ford Company (LOF) and

NHTSA entered into a cooperative research agreement for designing and manufacturing advanced glazing systems in support of this research program. Critical to the success of this cooperative research program was the selection of an appropriate vehicle door system for study. This selection was based on the availability of molds at LOF, the availability of doors for testing, and the characteristics of the specific door selected. A Chevrolet C/K Pickup door/window was selected. This window has encapsulated side edges that simplifies the modification of the glazing system. The C/K side window allows the use of a 5 mm thick glazing which is desirable for testing laminated side windows. Additionally, the C/K side window is significantly larger than the Ford LTD side window, thereby providing a larger surface area for testing. In addition to the design of the door modifications, the cooperative research agreement included the development, manufacture and testing of bilaminate (glass-plastic), trilaminate (glass-plastic-glass), and polycarbonate (rigid plastic) window materials.

A second cooperative research agreement was also initiated under the advanced glazing research program. In 1996, NHTSA, PPG Industries, and the General Services Administration, (GSA), initiated a small fleet study to evaluate the performance of bilaminate and trilaminate side windows. The goal of this study was to evaluate the in-use behavior of laminated side windows. The fleets were selected in order to find vehicles that were driven regularly and subjected to a wide variety of climates. Inspections were to be conducted approximately every six months to physically inspect the windows and interview the drivers. Forty-eight driver side windows were installed in government vehicles, mostly military police vehicles, in three locations on the east coast. Approximately equal numbers of trilaminate and bilaminate were installed at each location. The locations chosen were Ft. Drum, NY, Washington, DC, and Orlando, FL. The military vehicles are generally high mileage vehicles, often used 24 hours a day. While the GSA furnished vehicles are generally only in use for 2 to 3 years, it was felt that these vehicles can provide significant insight into the durability of the laminated side windows.

During the first inspection by PPG and NHTSA, after six months of use, dimples or dents appeared in the top edge of some of the laminated side windows. These dimples were caused by a tack weld in the window channel which contacted the top edge of the glazing when the window was closed. Repeated raising and lowering of the side window forced the raised section of the weld between the glass layers of the trilaminate side windows. While these dimples did not affect the performance of the window in any way, it was felt that the indentation could lead to long term durability issues, water encroachment, or possible delamination. Most of these vehicles were modified to flatten the surface of the tack weld and eliminate the localized contact with the window edge. At least one of these vehicles in each of the three areas was left unmodified.

After one year of service, one bilaminate window had a visible scratch. None of the military police using this vehicle were aware of the scratch, however it was observed by the inspector from PPG Industries. One trilaminate side window was broken during the replacement of the window regulator and the window was replaced with a new trilaminate side window. After one year of service, the mileage for the vehicles in this study ranged from 5,000 to 33,000 with an average of 17,000 miles. While this study is still underway, it is hoped that this cooperative research program may provide some insight to the in-use durability of bilaminate and trilaminate side windows.

1.2 Problem Definition

The previous status report on this project estimated the problem definition based on 1988 through 1993 NASS data adjusted to 1993 FARS. This previous work has been updated using the most recent five years of NASS data, 1992 through 1996, adjusted to 1996 FARS, and is included in the Appendix of this report. Between these two reporting periods, the number of fatalities associated with partial and complete ejections through windows has reduced from 25 to 22 percent of all the light vehicle fatalities. The average number of complete ejections through windows associated with fatalities increased from 3,536 to 3,970. Partial ejections through windows associated with fatalities decreased from 3,956 to 3,288 fatalities. The distribution of ejection routes has not significantly changed for complete ejections, while the number of partial ejections through front side windows decreased from 59 to 50 percent of all partial ejections. Overall, as shown in the Appendix, the general ejection problem has not changed dramatically between the reporting periods covered by the previous and current status reports.

2.0 OBJECTIVE

The purpose of this report is to document the research conducted to evaluate the feasibility of using advanced glazing systems to prevent occupant ejection in motor vehicle crashes. Component level impact tests were performed to evaluate potential ejection mitigating side door glazing systems, and to refine test procedures for that purpose. These systems were then tested, using the free-motion headform (FMH), to evaluate their head injury causing potential, as compared to standard tempered glass. Also, a series of sled tests was conducted to evaluate any increased potential for neck injury by the use of advanced glazing systems. Finally, the benefits and cost estimate figures from the previous status report have been updated to reflect more current crash data and expanded analysis methods.

3.0 ADVANCED SIDE GLAZING SYSTEM

3.1 Side Glazing Candidates

The glazing materials were selected to evaluate a range of glazing characteristics and any effect they may have on ejection mitigation or occupant impact injury. Other potential safety concerns such as laceration, entrapment, or durability were not evaluated in this report. Many of these safety concerns are addressed by the existing standards for automotive glazings.

The bilaminate glazing used is commercially known as *Sentry-Glas*. This product consists of a 4mm tempered glass outer layer and a 0.9 mm plastic film on the inside. The plastic film consists of two polymers bonded together resulting in the desired performance properties[1]. Two trilaminate glazing materials were tested. The only difference between the two glazings was the type of polyvinyl butyral (PVB) used for the inside, or middle, layer. Both a high penetration resistant (HPR) PVB formula, similar to a windshield construction (HPR trilaminate), and a higher adhesion PVB formula (non-HPR trilaminate) were used for the trilaminate glazing. The construction consisted of two 1.84 mm glass plys sandwiching a 0.76 mm PVB film. The trilaminate glass plys were heat strengthened. Heat-strengthened glass has characteristics somewhere in between fully tempered and annealed glass. Heat strengthening the glass allows for the thinner glass plys to provide adequate strength while keeping the same overall thickness as that of standard tempered glass. The third type of glazing was polycarbonate, a monolithic rigid plastic that was thermoformed to match the curvature of the standard tempered glass part. It was not treated with an abrasion resistant hard coating.

3.2 Window Encapsulation

It was decided that LOF would modify the existing mold used to encapsulate the vertical edges of the General Motors C/K Pickup truck. The production side windows from these 1998 model year vehicles are encapsulated along the vertical edges that fit inside the A and B-pillar so as to make the glazing "flush" with the door and window frame.

The resulting injection molded (RIM) system is shown in Figure 3.1. A T-edge design allowed for both vertical edges to fit in the C-channel of the door window frame. This results in increased penetration resistance because impact loads were transferred to the door frame. In addition, the top and diagonal edges of the window were encapsulated to provide additional rigidity. For this design, the weather-stripping was removed.

3.3 Modified C/K Pickup Door Window Frame

Modifications to the door window frame were required to transfer the load to the vehicle door. The simplistic design of the C/K window frame along with the T-edge section afforded a simple modification in which 20-gage sheet metal was bent around the interior and exterior sides of the C-channel and was welded in place. This modification was made along only the vertical edges of the frame above the belt line.

With the weather-stripping removed, the top and diagonal window edges rested against the door frame. Any loading would simply push these edges away, allowing an opening to occur. A U-channel was simulated by adding sheet metal to the exterior of both edges. The resulting door window frame modification is shown in Figure 3.2. Although it was necessary to remove the weather-stripping, this modification did not restrict the window's ability to be raised and lowered.

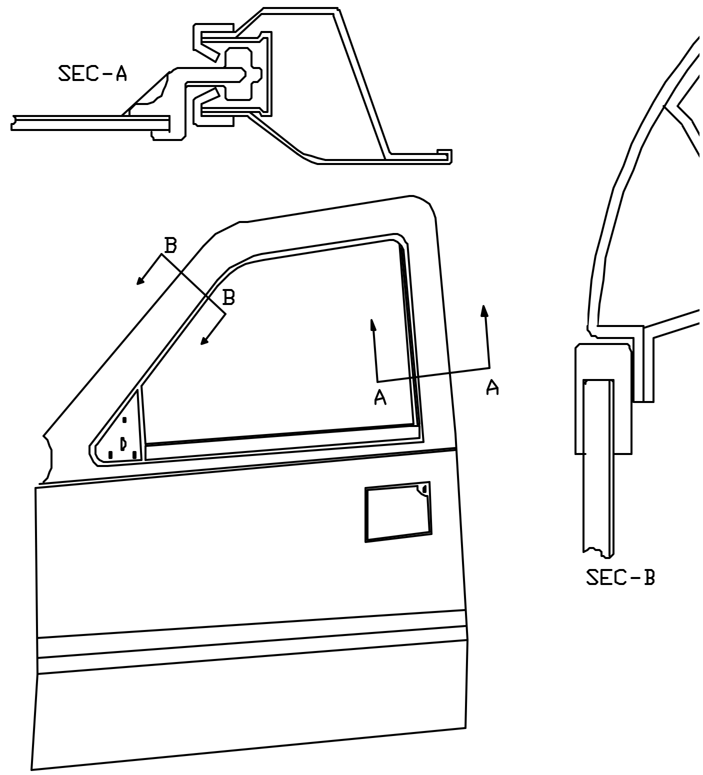

Figure 3.1 – Encapsulation Design for Alternative Glazings

Figure 3.2 – Door Window Frame Modification – Final

4.0 OCCUPANT RETENTION ASSESSMENT TESTING

4.1 Test Description and Results

The previous advanced glazing status report[1] detailed the development of an impactor designed to replicate the loading of an occupant's head and shoulder during typical ejection situations. This impactor weighs 18.3 kg (40 lbs) and is ovoid is shape to represent the contact area of an occupants head / shoulder complex. This test was used as a component test to determine if a glazing/door system can retain an

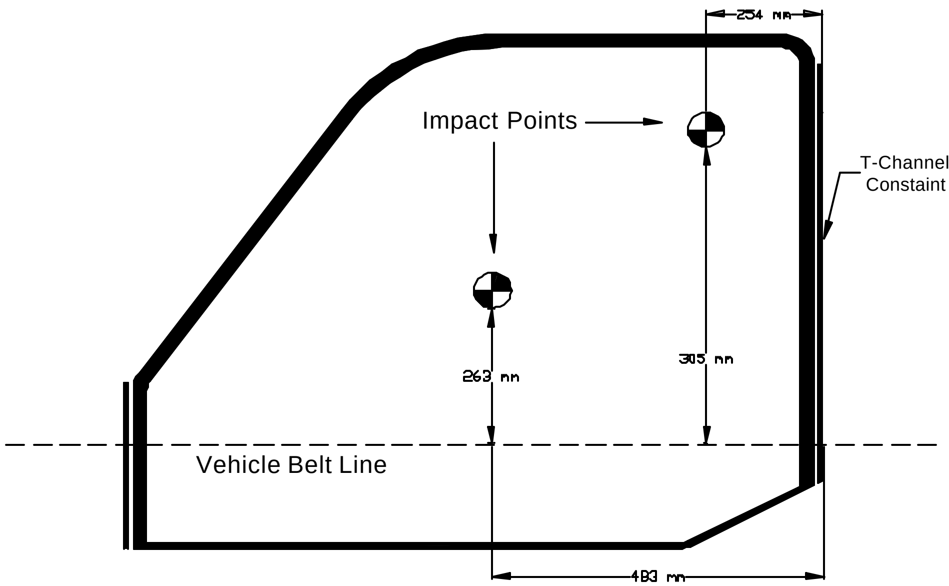

Figure 4.1 – Glazing Impact Locations

occupant. This test was demonstrated to be highly repeatable with very controlled test conditions. The range of impact speeds for the test device was selected by reviewing rollover test films and side impact crash data. Seven rollover tests had head to glazing contact with an average impact speed of 11.3 kmph (7.0 mph). For side impact crashes, the NASS crash data for lateral change in velocity for cases where the side glazing disintegrated due to occupant contact was evaluated. The lateral change in velocity of the vehicle is an upper bound on the occupant into glazing impact speed. The average lateral change in velocity was 17.8 kmph (11.1 mph). A range of impact speeds from 16.1 kmph (10 mph) to 24.1 kmph (15 mph) was selected.

A series of impact tests using the 18 kg (40 lb) retention impactor was conducted on the C/K Pickup door/ advanced glazing systems to determine if the modified T-edge encapsulation was capable of retaining the glazing material in the window frame without failure of the bond at the interface or failure of the door window frame modifications. The impactor was launched horizontally with respect to the ground. There were two targeted impact regions: the centermost point on the glazing area and a point in the upper, rear area of the glazing, near the B-pillar (see Figure 4.1). This latter point coincided with the impact area where the dummy's head struck the glazing in full dummy sled testing, which will be discussed later.

Variations to the window encapsulation and the frame were tested and analyzed. The modifications were all intended to prevent the top and diagonal edges of the window from being pushed out and thereby providing an ejection path. The encapsulation modifications included adding a steel reinforcing rod to various places in the mold and replacing the polyurethane molded along the top and diagonal edges with a clear polycarbonate strip of various widths. This last modification was thought to increase the aesthetics of a framed side window. Variations in the door window frame included varying the depth of the C-channel along the top and diagonal edges and increasing the channel depth at the transition between the top and diagonal edges. For each test, the bottom edge of the window was constrained by the standard C/K window regulator. The door frame modifications were designed to primarily to enhance occupant retention. Production feasibility and consumer acceptability were considered but not evaluated. Also, both the window encapsulation and the C-channel can be impacted by an occupant near a partially or fully open window. The potential disbenefits due to these impacts were not evaluated in this report. The results of the 18 kg guided impactor tests are summarized in Table 4.1.

A linear potentiometer recorded the impactor displacement measured from first contact with the glazing through maximum dynamic displacement. This measurement was a combination of both the glazing material and door window frame deflection. The final column of Table 4.1 (labeled "containment extent") was a measurement of the extent of disengagement between the encapsulation material and the modified window frame channel. A containment percentage was calculated by measuring the amount of glazing/encapsulation mold that had pulled free from the window frame along the top and diagonal edges and the vertical A and B-pillar edges. The bottom edge always remained firmly attached to the window regulator throughout the test matrix. Any penetration of the impactor and resulting tearing of the plastic material is noted separately. In all tests, the impactor was brought to rest by the modular glazing system well before reaching the physical 'stops' on the impactor's guidance system, whether penetration through the glazing occurred or not.

4.2 Discussion of Results

In addition to the C-channel modification to the vertical edges of the door window frame (see section 3.3), the top and diagonal edges were modified by adding sheet metal to simulate a U-channel. As listed in Table 4.1, the initial depth of this U-channel was nominally 25 mm (1") (see Figure 4.2). The results of the first test (CK02) indicated that additional support was necessary to contain the glazing since only 25 percent of the glazing perimeter was contained in the window frame. It was found that the transition area between the top edge and the diagonal edge was a weak point, so the
next modification was to add a reinforcement of 13 mm (½") to this area (see Figure 4.3). The test of this system (CK03) resulted in significantly improved containment (80 percent). Based on the results of tests CK04 through CK06 a U-channel depth of 25 mm and a transition area reinforcement of an additional 25 mm were used in test CK07. This produced 100 percent containment (see Figure 4.4). It was then discovered that the fabrication method used to modify the door window frames caused some portions of the encapsulation to melt and adhere to the sheet metal. The fabrication method was then changed to eliminate this occurrence and test CK08 was performed using the same modification levels as test CK07. This test resulted in a significant reduction in performance, with a glazing containment of only 25 percent. This demonstrated that the melting of the encapsulation had caused artificially high containment levels, so tests CK02 through CK07 were considered invalid. They are included in this discussion since based on those results, weakness at the transition area was identified. The 25 mm reinforcement to this area was used in all subsequent tests.

Table 4.1 -- Retention Test Results (18 kg Impactor)

TEST NO.	CONFIGURATION	DOOR FRAME MODIFICATION	IMPACT LOCATION	TEST VELOCITY kmph (mph)	MAXIMUM DEFLECTION mm (in.)	CONTAINMENT EXTENT
CK02*	Bilaminate (full urethane edge with wire reinforcement)	25 mm U-channel depth	Center	24.3 (15.1)	178 (7.0)	Top, diagonal and A-pillar edge pulled out (28% containment)
CK03*	Bilaminate (full urethane edge)	same as CK02, plus 13 mm reinforcement at transition point	Center	24.3 (15.1)	165 (6.5)	Part of top edge pulled out (80 % containment)
CK04*	Bilaminate (full urethane edge)	same as CK02, except reduced reinforcement at transition point	Center	24.3 (15.1)	No Data Recorded	Part of top and diagonal edge pulled out (63% containment)
CK05*	Bilaminate (full urethane edge)	same as CK03	Center	24.1 (15)	No Data Recorded	Part of top and diagonal edge pulled out (90% containment)
CK06*	Bilaminate (full urethane edge)	same as CK03	Center	19.9 (12.4)	No Data Recorded	(100% containment); no tearing of plastic inner layer
CK07*	Bilaminate (full urethane edge)	same as CK02, plus 25 mm reinforcement at transition point	Center	20.3 (12.6)	168 (6.6)	(100% containment); no tearing of plastic inner layer
CK08	Bilaminate (full urethane edge with wire reinforcement)	same as CK07	Center	24.3 (15.1)	206 (8.1)	Top, diagonal and part of B-pillar edge pulled out (25% containment)
CK09	Bilaminate (full urethane edge with wire reinforcement)	same as CK07	Center	20.3 (12.6)	224 (8.8)	Part of top and diagonal edge pulled out (60% containment)
CK10	Bilaminate (full urethane edge with wire reinforcement)	same as CK07, but with 50 mm U-channel depth	Center	24.3 (15.1)	193 (7.6)	(100% containment); no tearing of plastic inner layer
CK11	Non-HPR Trilaminate (full urethane edge)	same as CK07, but with 38 mm U-channel depth	Center	24.3 (15.1)	187 (7.4)	Headform completely penetrated glazing
CK12	Bilaminate (full urethane edge with wire reinforcement)	same as CK11	Center	24.3 (15.1)	193 (7.6)	Part of top and diagonal edge pulled out (55% containment)

Table 4.1 -- Retention Test Results (18 kg Impactor) (Continued)

TEST NO.	CONFIGURATION	DOOR FRAME MODIFICATION	IMPACT LOCATION	TEST VELOCITY kmph (mph)	MAXIMUM DEFLECTION mm (in.)	CONTAINMENT EXTENT
CK13	Non-HPR Trilaminate (full urethane edge)	same as CK11	Center	19.5 (12.1)	185 (7.3)	(100% containment); significant tearing of plastic inner layer
CK14	Bilaminate (76 mm polycarbonate)	same as CK11	Center	23.6 (14.7)	157 (6.2)	(100% containment); no tearing of plastic inner layer
CK15	Polycarbonate (full urethane edge)	same as CK11	Center	23.6 (14.7)	173 (6.8)	(100% containment)
CK16	Bilaminate (76 mm polycarbonate)	same as CK11	Center	23.8 (14.8)	127 (5.0)	(100% containment); no tearing of plastic inner layer
CK17	HPR Trilaminate (full urethane edge)	same as CK11	Center	23.8 (14.8)	234 (9.2)	(100% containment); partial tearing of plastic inner layer
CK18	HPR Trilaminate (38 mm polycarbonate)	same as CK11	Center	23.8 (14.8)	103 (4.5)	(100% containment); no tearing of plastic inner layer
CK19	HPR Trilaminate (full urethane edge)	same as CK11	Center	23.8 (14.8)	249 (9.8)	(100% containment); no tearing of plastic inner layer
CK20	Polycarbonate (full urethane edge)	same as CK11	Center	23.8 (14.8)	No Data Recorded	Part of top edge pulled out (92% containment)
CK24	Bilaminate (full urethane)	same as CK11	Corner	23.8 (14.8)	186 (7.3)	Part of top edge pulled out (75% containment)
CK25	HPR Trilaminate (full urethane edge)	same as CK11	Corner	23.3 (14.4)	No Data Recorded	(100% containment); no tearing of plastic inner layer
CK26	HPR Trilaminate (full urethane edge)	same as CK11	Corner	22.7 (14.1)	154 (6.1)	(100% containment); no tearing of plastic inner layer
CK27	Polycarbonate (full urethane edge)	same as CK11	Corner	23.3 (14.5)	175 (6.9)	(100% containment)

*Artificially high containment levels. See discussion in Section 4.2.

Figure 4.2 – Door Window Frame Modification – Test CK02

Figure 4.3 – Door Window Frame Modification – Test CK03

Figure 4.4 – Door Window Frame Modification – Test CK05

Based on the results of tests CK08 and CK09, the U-channel was extended an additional 25 mm, giving a total channel depth of 51 mm (2") (Figure 4.5). The test of this system (CK10) produced 100 percent containment without any tearing of the plastic layer of the bilaminate glazing. Although this 51 mm channel resulted in excellent glazing containment, it was felt that other design considerations would suggest a smaller channel. Based on the testing to this point, it was not felt that a channel depth of 25 mm could produce acceptable containment results with the alternative glazings and encapsulation designs used in this program, but that this may be possible with a 38 mm (1½") channel depth. Therefore, the U-channel depth along the top and diagonal edges was reduced to 38 mm for all subsequent testing.

Figure 4.5 – Door Window Frame Modification – Test CK10

There are a number of observations that can be made based on the results of the tests conducted with a U-channel depth of 38 mm and a transition area reinforcement of 25 mm. First, the non-HPR trilaminate did not have sufficient strength to contain the 18 kg impactor at 24 kmph (15 mph). In this test (CK11), the impactor punched through the plastic inner layer of the trilaminate, thus allowing complete headform penetration. Even when the impact speed was reduced to 19½ kmph (12 mph), the 18 kg impactor significantly tore the inner plastic layer allowing partial headform penetration (CK13).

The bilaminate offered more penetration resistance and glazing containment than the non-HPR trilaminate, especially when a 76 mm (3") strip of polycarbonate was bonded to its top and diagonal edges instead of the urethane molded encapsulation (even with wire reinforcement). In 24 kmph impacts to the center of the glazing, the polycarbonate strip produced 100 percent glazing containment, as compared to 55 percent for the urethane edges (tests CK12, CK14, and CK16). When the upper rear corner of the glazing was impacted, the urethane edges (without wire reinforcement) produced 75 percent containment (CK24). None of these tests resulted in tearing of the plastic layer.

Both the HPR trilaminate and polycarbonate glazings offered excellent penetration resistance and glazing containment. Three tests were run using the urethane edges (without wire reinforcement) on the polycarbonate - two to the center of the glazing (CK15 and CK20) and one to the upper rear corner (CK27). These produced 100 percent, 92 percent, and 100 percent glazing containment, respectively, without glazing fracture. Five tests were performed using the HPR trilaminate - two center impacts with the urethane edges (CK17 and CK19), two upper corner impacts with the urethane edges (CK25 and CK26), and one center impact with 38 mm wide polycarbonate edges (CK18). All of these tests resulted in 100 percent containment. In one of these, there was partial tearing of the plastic inner layer, while there was no tearing in the other four.

The discussion to this point has focused on the performance of the glazing systems based on their penetration resistance and glazing containment. Another performance measurement taken during these tests was maximum dynamic impactor deflection (from the time of first contact with the glazing). This is also an important parameter in that it is the direct measure of impactor (i.e. occupant) excursion beyond the perimeter of the vehicle. Limiting deflection, and thus head excursion, will reduce the potential for contact with the ground during rollovers, or a striking vehicle in a near side impact. The tempered glass materials commonly in use for side windows do not deform significantly before shattering. Note that the maximum deflection does not necessarily relate to glazing containment or penetration resistance. For example, in test CK12, the bilaminate glazing was only 55 percent contained, with a deflection of 193 mm (7.6"). In test CK19, the HPR trilaminate was 100 percent contained (without plastic tearing), but the maximum deflection was 249 mm (9.8"). As a second example, in test CK10, the bilaminate glazing was 100 percent contained (without plastic tearing), with a maximum deflection of 193 mm (7.6"). In test CK11, the non-HPR trilaminate was completely penetrated by the impactor, but the maximum deflection was 187 mm (7.4"). Therefore, it is likely that to fully evaluate the ejection resistance capability of a glazing system, its performance must be judged based on penetration resistance, glazing containment, and maximum impactor deflection.

Based on these results, the bilaminate, HPR trilaminate, and polycarbonate alternative side glazings evaluated in this study were capable of containing an impact from an 18 kg impactor at a speed of 24 kmph, when appropriate encapsulation methods and door modifications were used. Also, it appears that such encapsulation methods and door modifications are possible.

Another factor that was evaluated was the effect of impact location on the retention test results. Comparable tests were conducted using the bilaminate, HPR trilaminate, and polycarbonate glazings in which the center and upper rear corner impact locations were struck. In all these tests, full urethane encapsulation was used on the top and diagonal edges of the glazing. The only difference was that for the bilaminate center impacts, these edge molding also included a wire reinforcement. Since that reinforcement did not appear to have a significant effect on the performance of the glazing system, it was included in this comparison. As shown in Table 4.2, penetration resistance and glazing containment were the same or better, and maximum deflections were essentially the same or lower in the corner impacts. Based on these limited data, it would appear that the center impact location presented a somewhat greater challenge for retention performance.

Table 4.2 -- Comparison of Center and Upper Rear Corner Impact Locations
Full Urethane Edges

Glazing Type	Penetration		Containment		Maximum Deflection (mm)	
	Center	Corner	Center	Corner	Center	Corner
Bilaminate	No Tear	No Tear	55%	75%	193	186
HPR Trilaminate	Partial Tear/No Tear	No Tear	100% 100%	100%	234, 249	154
Polycarbonate	No Fracture	No Fracture	100%, 92%	100%	173	175

Finally, the data listed in Table 4.1 are too limited to reach any conclusions regarding test repeatability. Four pairs of identical tests were conducted. Tests CK14 and CK16 were of the bilaminate with the 76 mm (3") polycarbonate strip bonded to the top and diagonal edges, impacted in the center at 24 kmph. In both tests, 100 percent containment was achieved without any tearing of the plastic layer. The maximum deflections were 157 mm (6.2") and 127 mm (5.0"), respectively, resulting in a variation of ±10.6 percent, which was higher than desired. Tests CK17 and CK19 were of the HPR trilaminate with full urethane edges, impacted in the center at 25 kmph. In both tests, 100 percent containment was achieved, but there was a partial tear of the plastic layer in the first test. The maximum deflections were 234 mm (9.2") and 249 mm (9.8"), respectively, which was a very low variation of ± 3.1 percent. Tests CK15 and CK20 were of the polycarbonate with full urethane edges, impacted in the center at 24 kmph. The first test produced 100 percent containment, while that for the second was 92 percent, and no glazing fracture occurred in either test. Unfortunately, the deflection data were lost for the second test, so no comparison was possible. The last pair of tests, CK25 and CK26, were of the HPR trilaminate with full urethane edges, impacted in the upper rear corner at 24 kmph. Both tests achieved 100 percent containment without tearing of the plastic layer. As for the previous pair of tests, no comparison of maximum deflection was possible since that data were lost in the second test.

The feasibility of using advanced glazing systems to prevent occupant ejection depends heavily on the practicability of the proposed door modifications. One problem with the proposed designs is they are not applicable to vehicles with frameless side windows. In particular, convertibles and vehicles with removable t-top roofs do not have window frames and the proposed designs are not applicable to these vehicles. It is difficult to determine the exact number of vehicles that have frameless windows, but there is a significant minority of passenger cars which have minimal, backless or no window frame. The proposed door modifications either would require significant redesign or would not be applicable to these vehicles. For framed windows, some additional work is still needed to further examine the appropriate depth of the proposed U channel design.

5.0 HEAD INJURY ASSESSMENT TESTING

5.1 Test Description and Results

A series of free-motion headform (FMH) tests was conducted on the advanced glazing systems as well as on standard tempered glass side windows. In addition to the standard C/K Pickup side window, standard side windows from a 1993 Honda Civic and 1991 Dodge Caravan were also tested. The FMH established for use in the 1995 upgrade of FMVSS 201 was used[2]. The FMH is a Hybrid III head, weighing 4.5 kg (10 lbs.), modified for use as a free-motion impactor. The headform was instrumented with a triaxial accelerometer array located at the center of gravity. The accelerometers used were Endevco's model 2262ca-2000 'damped' units. Headform acceleration data were collected in the x, y, and z-directions as a function of time in accordance with SAE Recommended Practice J211.

The test setup consisted of the impactor and glazing/door system attached to the vehicle (see Figure 5.1). This setup simulated real world conditions by allowing the dynamic deflection of the door frame. There were two targeted impact locations for each glazing type, similar to those in the guided impactor testing. For each glazing type and impact location, multiple tests were conducted to generate an understanding of the repeatability of this type of glazing testing. The results from this testing are presented in Table 5.1.

Figure 5.1 – Test Setup – FMH Impactor

Table 5.1 -- Free-Motion Headform Test Results

TEST NO.	GLAZING DESCRIPTION	IMPACT LOCATION	VELOCITY kmph (mph)	HIC (36 ms)	RESULTS
2520036	Tempered Side Glass *1993 Honda Civic*	Center	23.5 (14.6)	249	No glass breakage
2520037	Tempered Side Glass *1993 Honda Civic*	Center	23.5 (14.6)	238	No glass breakage
2520038	Tempered Side Glass *1993 Honda Civic*	Center	23.5 (14.6)	97	Glass shattered upon impact
2520039	Tempered Side Glass *1993 Honda Civic*	Center	23.5 (14.6)	45	Glass shattered upon impact
2520040	Tempered Side Glass *1993 Honda Civic*	Corner	23.6 (14.7)	186	No glass breakage/top and side edge pushed out of frame
2520041	Tempered Side Glass *1993 Honda Civic*	Corner	23.6 (14.7)	145	No glass breakage/top and side edge pushed out of frame
2520042	Tempered Side Glass *1993 Honda Civic*	Corner	28.2 (17.5)	106	Glass pushed out of frame and shattered
2520043	Tempered Side Glass *1993 Honda Civic*	Corner	28.2 (17.5)	221	Glass pushed out of frame and shattered
2520044	Tempered Side Glass *1993 Honda Civic*	Corner	28.2 (17.5)	423	No glass breakage
2520045	Tempered Side Glass *1993 Honda Civic*	Corner	28.5 (17.7)	428	No glass breakage
2520046	Tempered Side Glass *1993 Honda Civic*	Corner	28.5 (17.7)	85	Glass shattered upon impact
2520047	Tempered Side Glass *1993 Honda Civic*	Corner	28.0 (17.4)	73	Glass shattered upon impact
2520048	Tempered Side Glass *1993 Honda Civic*	Corner	28.0 (17.4)	78	Glass shattered upon impact
2520054	Tempered Side Glass *1991 Dodge Caravan*	Center	23.8 (14.8)	50	Glass shattered upon impact
2520055	Tempered Side Glass *1991 Dodge Caravan*	Center	23.5 (14.6)	59	Glass shattered upon impact
2520056	Tempered Side Glass *1991 Dodge Caravan*	Center	23.6 (14.7)	34	Glass shattered upon impact
2520057	Tempered Side Glass *1991 Dodge Caravan*	Corner	23.6 (14.7)	66	Glass shattered upon impact
2520058	Tempered Side Glass *1991 Dodge Caravan*	Corner	23.8 (14.8)	154	No glass breakage
2520059	Tempered Side Glass *1991 Dodge Caravan*	Corner	23.8 (14.8)	159	No glass breakage
2520060	Tempered Side Glass *1991 Dodge Caravan*	Corner	24.0 (14.9)	162	No glass breakage
2520061	Tempered Side Glass *1991 Dodge Caravan*	Corner	24.0 (14.9)	163	No glass breakage
2520062	Tempered Side Glass *1991 Dodge Caravan*	Corner	28.5 (17.7)	240	No glass breakage
2520063	Tempered Side Glass	Corner	28.5 (17.7)	325	No glass breakage

Table 5.1 -- Free-Motion Headform Test Results (con't)

TEST NO.	GLAZING DESCRIPTION	IMPACT LOCATION	VELOCITY kmph (mph)	HIC (36 ms)	RESULTS
2520064	Tempered Side Glass *C/K Pickup*	Center	23.6 (14.7)	52	Glass shattered upon impact
2520065	Tempered Side Glass *C/K Pickup*	Center	23.8 (14.8)	73	Glass shattered upon impact
2520066	Tempered Side Glass *C/K Pickup*	Center	23.6 (14.7)	170	Glass shattered upon impact
2520091	Tempered Side Glass *C/K Pickup*	Corner	23.3 (14.5)	157	No glass breakage
2520092	Tempered Side Glass *C/K Pickup*	Corner	23.3 (14.5)	157	No glass breakage
2520099	Tempered Side Glass *C/K Pickup*	Corner	28.2 (17.5)	227	No glass breakage/top edge pushed out of frame
2520100	Tempered Side Glass *C/K Pickup*	Corner	28.5 (17.7)	154	Glass shattered upon impact
2520101	Tempered Side Glass *C/K Pickup*	Corner	28.5 (17.7)	265	No glass breakage/top edge pushed out of frame
2520067	Polycarbonate	Center	23.8 (14.8)	263	No damage
2520068	Polycarbonate	Center	23.8 (14.8)	227	No damage
2520069	Polycarbonate	Center	23.6 (14.7)	232	No damage
2520070	Polycarbonate	Center	19.6 (12.2)	225	No damage
2520071	Polycarbonate	Center	19.6 (12.2)	222	No damage
2520072	Polycarbonate	Center	29.0 (18.0)	399	No damage
2520073	Polycarbonate	Center	28.8 (17.9)	368	No damage
2520087	Polycarbonate	Corner	23.5 (14.6)	146	No damage
2520088	Polycarbonate	Corner	23.5 (14.6)	151	No damage
2520075	HPR Trilaminate	Center	23.6 (14.7)	143	No glass breakage
2520076	HPR Trilaminate	Center	24.1 (15.0)	153	No glass breakage
2520077	Non-HPR Trilaminate	Center	29.0 (18.0)	246	Glass shattered upon impact
2520078	Non-HPR Trilaminate	Center	28.8 (17.9)	146	Glass shattered/partial tear
2520089	HPR Trilaminate	Corner	23.6 (14.7)	103	Glass shattered upon impact
2520090	HPR Trilaminate	Corner	23.3 (14.5)	99	Glass shattered upon impact
2520079	Bilaminate	Center	29.0 (18.0)	297	Glass shattered upon impact
2520080	Bilaminate	Center	23.6 (14.7)	163	Glass shattered upon impact
2520081	Bilaminate	Center	23.6 (14.7)	161	Glass shattered upon impact
2520082	Bilaminate	Corner	23.3 (14.5)	112	Glass shattered upon impact
2520083	Bilaminate	Corner	23.3 (14.5)	298	No glass breakage
2520084	Bilaminate	Corner	23.5 (14.6)	299	No glass breakage
2520085	Bilaminate	Corner	23.3 (14.5)	358	No glass breakage
2520086	Bilaminate	Corner	23.3 (14.5)	104	Glass shattered upon impact

5.2 Discussion of Results

A number of observations can be made based on the results of the FMH testing. One of the first was that, for a given glazing and impact configuration, the HIC responses were higher if the glass did not break. Table 5.2 lists the HICs of tests from four impact conditions in which repeat tests produced mixed results on whether the glass fractured or not. The HIC responses were from about 1½ to more than four times lower in the tests which produced glass fracture as compared to those that did not (based on average HICs). This is an important point to keep in mind when evaluating glazing systems for head injury causing potential. For a given glazing system and set of impact conditions, it is likely that maximum (or near maximum) HIC is achieved at the speed just below that which produces glazing fracture, and that increasing the impact speed in subsequent tests may not result in substantially higher HICs. Therefore, a critical factor in determining the true head injury causing potential of a glazing system may be the glazing's resistance to fracture.

Table 5.2 - Fracture vs. No Fracture Comparison

	HIC	
	Fracture	No Fracture
Honda Civic tempered glass center impact 24 kmph	97, 45	249, 238
Honda Civic tempered glass corner impact 29 kmph	85, 73 106*, 221*	423, 428
C/K Pickup tempered glass corner impact 24 kmph	154	227, 265
C/K Pickup bilaminate glazing corner impact 24 kmph	112, 104	298, 299, 358

* glass pushed out of the door frame before breaking

Another observation was that the impacts in the upper rear corner of the glazing (near the B-pillar) were less likely to produce glazing fracture than impacts to the center of the glazing. The HIC responses from all the (nominally) 24 kmph (15 mph) impacts to the center of the glazings are shown in Figure 5.2, while those for the 24 kmph impacts into the upper corner of the glazings are shown in Figure 5.3. Note that three of the six glazings tested in the center fractured for all tests conducted. The Civic tempered glass fractured in two of the four tests, while the polycarbonate and the HPR trilaminate did not fracture in any of these tests. For the impacts to the upper corner, only the HPR trilaminate fractured in all tests. The Caravan tempered window fractured in one of the five tests, while the bilaminate glazing fractured in two of the five tests. The other three glazings impacted did not fracture in any of these tests.

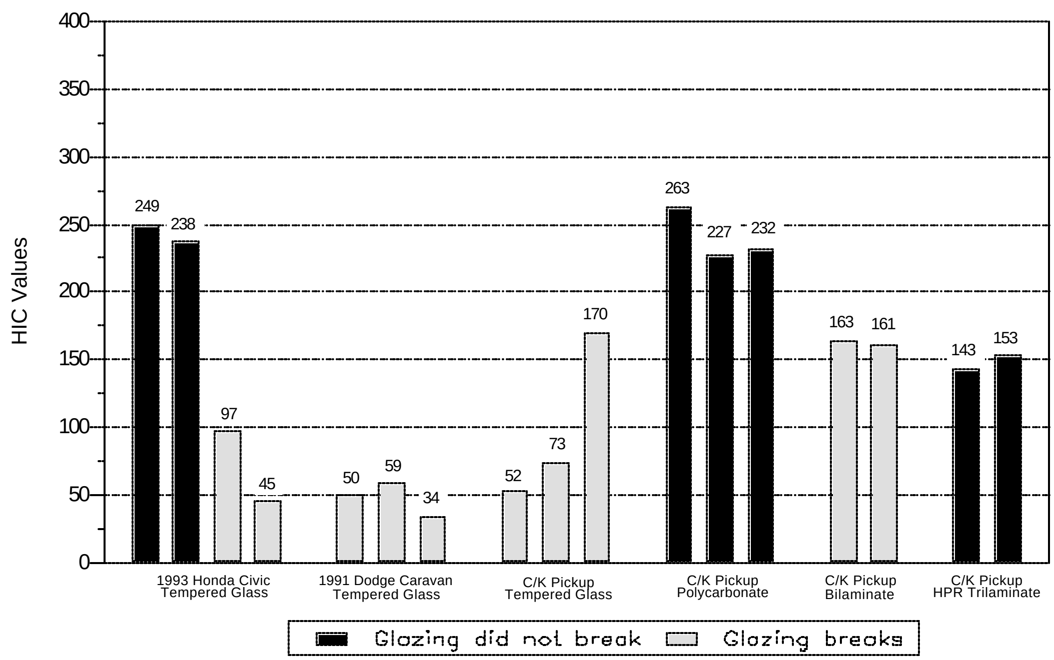

Figure 5.2 – HIC Responses-Center Impacts at 24 kmph

Generally, it appears that the proximity of the door frame to the upper rear corner impact location helped to distribute a portion of the impact force to the door frame, thereby stressing the glazing itself less, resulting in fewer fractures than in impacts to the center location. The exception to this was the HPR trilaminate, which did not fracture when impacted in the center, but did when struck in the upper corner location. The upper corner location often produced higher HICs than the center location, since an upper corner impact was less likely to result in glazing fracture. Interestingly, as shown in Table 5.3, in cases where the upper corner and center location impacts produced the same fracture result, the upper corner HIC responses were usually substantially lower.

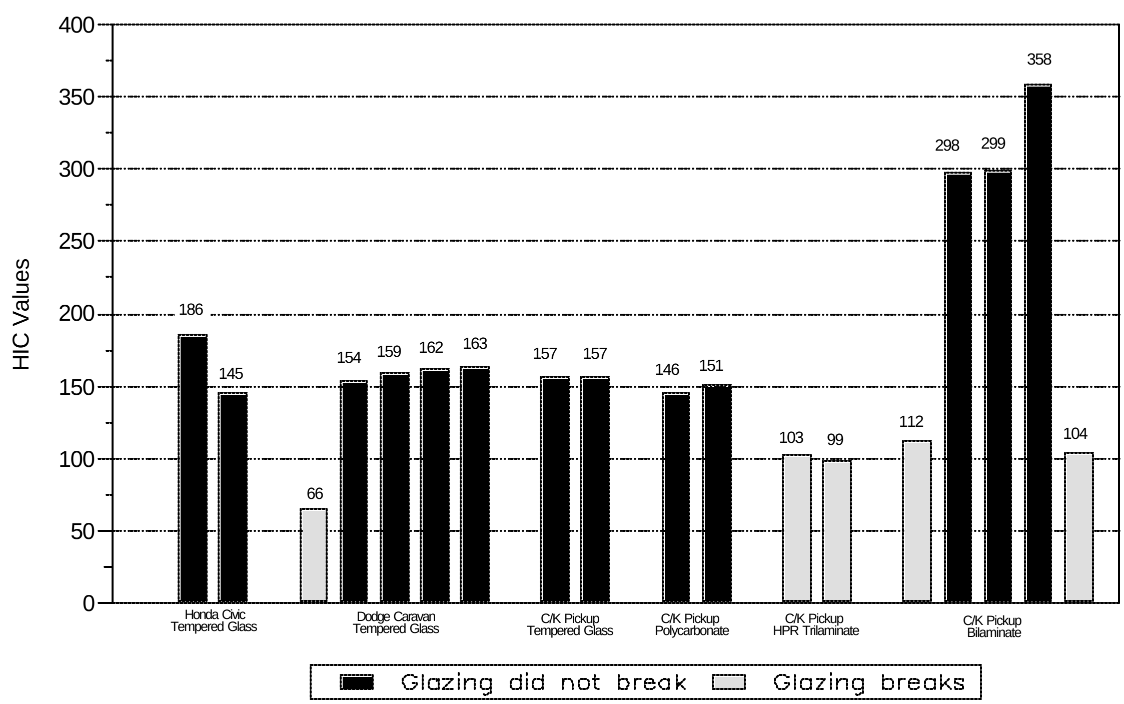

Figure 5.3 -- HIC Responses-Upper Rear Corner Impacts at 24 kmph

Table 5.3 -- HIC Comparison for Center and Upper Corner Impact Locations

	HIC	
	Center	Upper Corner
Honda Civic tempered glass no fracture 24 kmph	249, 238	186, 145
Dodge Caravan tempered glass fracture 24 kmph	50, 59, 34	66
C/K Pickup polycarbonate no fracture 24 kmph	263, 227, 232	146, 151
C/K Pickup bilaminate glazing fracture 24 kmph	163, 168	112, 104

Perhaps the most important observation from these FMH tests was that the alternative glazings tested did not necessarily produce higher HIC responses than the standard tempered glass side windows currently in use. In the 24 kmph impacts (see Figures 5.2 and 5.3), with the exception of three of the upper rear corner impacts to the bilaminate glazing, the highest HICs recorded were from impacts to the center of the Civic tempered window and to the center of the polycarbonate glazing, which were of essentially the same level. As for the bilaminate tests, two of the five tests produced fracture and relatively low HICs, while three did not produce fracture and resulted in HICs in the 300 to 350 range. Since some of these impacts produced fracture while others did not, this impact condition was clearly near the upper bound for this glazing. Impacts of slightly higher severity would be expected to produce fracture, most likely resulting in lower HICs.

Several tests were run at nominal speeds of 29 kmph (18 mph), and the HIC responses from these are shown in Figure 5.4. Note that the highest HICs recorded were from impacts to the standard Civic tempered side window. In these two tests (tests 2520044 and 2520045 in Table 5.1), the impact location was to the upper rear corner, the glazing did not break, and HICs of 423 and 428 were

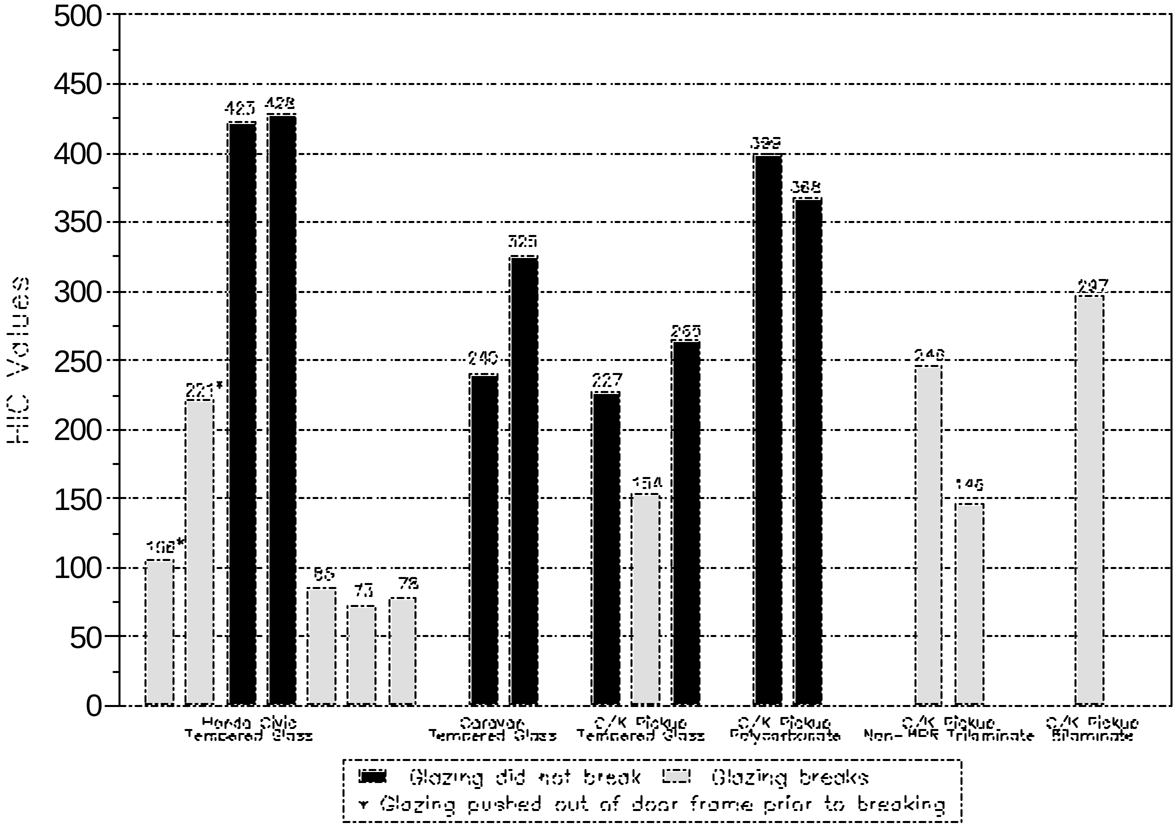

Figure 5.4 -- HIC Results-29 kmph Tests

produced. The next highest HICs were from impacts to the center of the polycarbonate glazing, which also did not fracture, and resulted in HICs of 399 and 368 (tests 2520072 and 2520073 in Table 5.1). Therefore, for impact speeds up to 29 kmph, it does not appear that these alternative side glazings present a higher risk of head injury than side glazings currently in use.

Finally, a number of repeat tests were conducted which allowed for an evaluation of the repeatability of the test procedure. In cases where repeat tests produced different fracture results (i.e. some fractured while others did not), there were generally large differences in the resulting HICs. Since impact speeds were consistent, it was felt that this variation was largely due to variations in the glazing systems and not the procedure itself. Therefore, this analysis was conducted using only sets of tests in which at least two tests were performed under the same impact conditions and produced the same fracture result. There are 23 such sets of tests listed in Table 5.1. The average coefficient of variation (c.v.) for these was 15.2 percent, which was higher than desired. Several of these had very low average HICs in which even small differences result in a relatively higher percentage variation. When only the eight sets of tests which produced an average HIC of 200 or more were considered, the average c.v. was 7.7 percent, which is considered good. Even when this sampling was expanded to include sets of tests with an average HIC of at least 150 (14 sets), the average c.v only rose to 12.0 percent, which is still acceptable.

The possibility of developing a transform to relate FMH HIC responses in glazing impacts to those from a full dummy was discussed in the November 1995 status report[1]. This has not been done. If the pass/fail limit for FMH HIC responses is to be based on an injury level, such a transform would likely be necessary. However, based on the results presented in this chapter, it may be possible to establish a pass/fail limit for HIC that simply requires advanced glazings to perform no worse than current tempered side windows. In that case, no transform would be necessary.

6.0 NECK INJURY ASSESSMENT TESTING

6.1 Test Description and Results

A series of HYGE sled tests was conducted to assess the potential for neck injury due to occupant contact with the advanced side glazing/modified doors. The approach was to compare the neck loads and moments of a full dummy from impacts into ejection mitigating glazings to those into standard tempered glass side windows.

The sled buck was similar to the test frame used in the component level testing (see Figure 6.1). It consisted of a C/K Pickup truck cab with a standard driver side door. The side door padding, arm rest, and trim were removed so that they would not interfere with the dummy's movement through the glazing area. A generic seat was fabricated that allowed the sled buck to accelerate under the dummy and strike the dummy at the specified speed. The SID/H-III anthropomorphic test device was chosen and instrumented with a six-axis upper neck load cell and accelerometers in the head, upper (T01) and lower (T12) spine, and upper and lower ribs.

Figure 6.1 -- Neck Injury Assessment Setup

For tests SID-01 through SID-11 (see Table 6.1) the dummy was originally positioned according to the seating procedure described in FMVSS 214. At this position, lateral movement into the side door structure would result in the back part of the dummy's head striking the rear area of the door frame or B-pillar. The seat was therefore moved forward until the head would contact only the glazing through the entire event. The resulting contact area is shown in Figure 4.1. The dummy was tipped 26E toward the window to ensure maximum loading to the head/neck by the glazing/door system. This seating position also ensured that the dummy's neck would be subjected to three potentially injurious loading conditions: lateral shear, axial compression, and a moment about the longitudinal (x-) axis. In order to approximate more closely the 18 kg loading condition used in the component level impact tests, the dummy was raised in the seat to provide simultaneous loading of the head and shoulder on the glazing material in tests SID-12 through SID-14. This was the loading condition used to calculate the effective mass in a rollover type impact as explained in the first glazing status report[1].

Table 6.1 -- Neck Injury Assessment Test Matrix

TEST NO.	GLAZING TYPE	LOADING CONDITION (1st Glazing Contact)	IMPACT SPEED kmph (mph)
Sid-01	C/K Tempered Glass	Head	24 (15)
Sid-02	C/K Tempered Glass	Head	24 (15)
Sid-03	C/K Tempered Glass	Head	16 (10)
Sid-04	non-HPR trilaminate Glass	Head	24 (15)
Sid-05	non-HPR trilaminate	Head	24 (15)
Sid-06	HPR trilaminate	Head	24 (15)
Sid-07	HPR trilaminate	Head	24 (15)
Sid-08	Bilaminate	Head	24 (15)
Sid-09	Bilaminate	Head	24 (15)
Sid-10	Polycarbonate	Head	24 (15)
Sid-11	Polycarbonate	Head	24 (15)
Sid-12	Polycarbonate	Head and Shoulder	24 (15)
Sid-13	Bilaminate	Head and Shoulder	24 (15)
Sid-14	HPR trilaminate	Head and Shoulder	24 (15)

The six-axis upper neck load cell recorded the longitudinal and lateral shear forces, axial tension and compressive forces, and moments about the x-, y- and z-axes. Occipital condyle moments were calculated in the same manner as for frontal impacts, except that the moment measured about the longitudinal axis was used rather than that about the lateral axis. Signal outputs of the neck transducer were filtered with Class 1000 for force and Class 600 for moments.

6.2 Discussion of Results

Peak values for lateral shear, axial compression and bending moment about the occipital condyle are shown in Figures 6.2, 6.3 and 6.4 respectively. [Note: FMVSS 208 uses a critical value for compressive neck loading (time duration = 0) for an average adult male of 4000 N. The values for fore/aft shear, flexion moment, and extension moment are 3100 N, 190 N-m, and 57 N-m, respectively]. The head impact caused the glass to break in every test (the polycarbonate windows did not fracture) but the ejection mitigating glazings remained entirely within the modified door frame (i.e. 100 percent containment). The plastic inner layer was torn in both tests involving the non-HPR trilaminate but the head did not penetrate. The plastic inner layer remained intact in the HPR trilaminate configuration.

The first observation from the results displayed in Figures 6.2 through 6.4 was that repeatability of neck loads and moments was generally not good. The variation in pairs of tests (i.e. plus or minus the percentage difference from average) averaged ±21.0 percent for the shear loads, ±16.3 percent for the axial loads, and ±15.1 percent for the moments. In each case, the responses from the tempered glass impacts were the least repeatable, with variations of ±64.0 percent, ±46.5 percent, and ±30.0 percent for the shear loads, axial loads, and moments, respectively. In fact, the lowest axial neck load measured in all the sled tests was 1553 N in one of the tempered glass impacts, while the second highest was 4253 N, from the repeat of that test. Unlike for the FMH tests discussed in the previous chapter, it cannot be reasonably assumed that this variability was due largely to the glazing systems themselves. While they were certainly one source of variability, the test procedure itself had a number of variables which could have contributed.

Despite this high variability and limited data, a few observations can be made regarding these tests. Generally, impacts into standard tempered glass resulted in lower shear loads and moments than those into the advanced glazings. In each case, the lowest responses measured were from the tempered glass impacts. Due to the high variability, this same statement cannot be made for the axial loads. No assessment of actual neck injury levels due to shear loads or moments was made since no accepted lateral neck injury criteria exist. Another observation was that the test configuration in which the head and shoulder struck the glazing simultaneously produced lower loads and moments than that in which the head struck first.

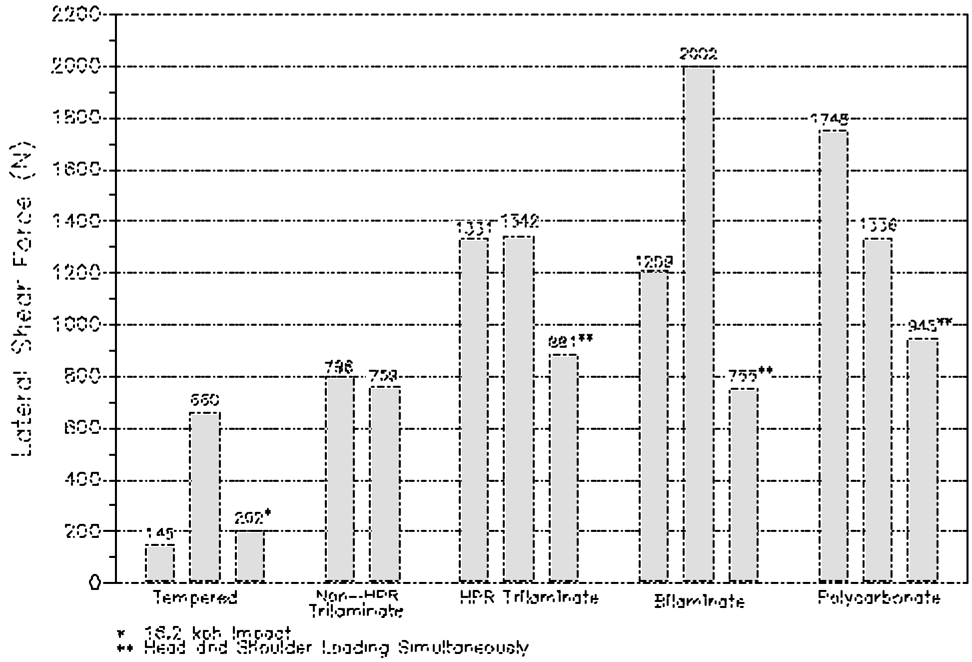

Figure 6.2 -- Lateral Shear Force Measurements

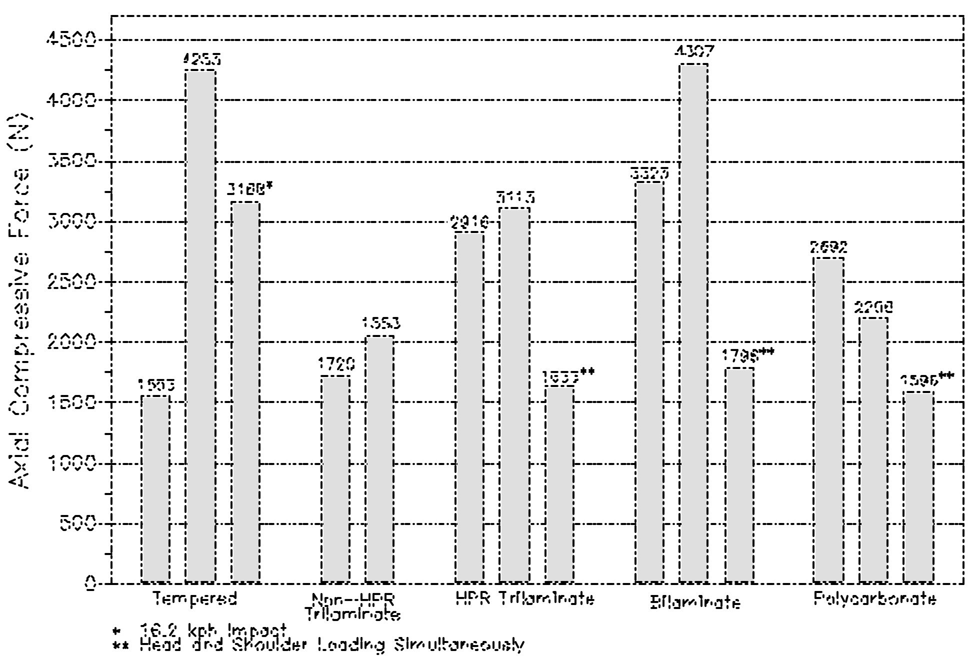

Figure 6.3 -- Axial Compressive Force Measurements

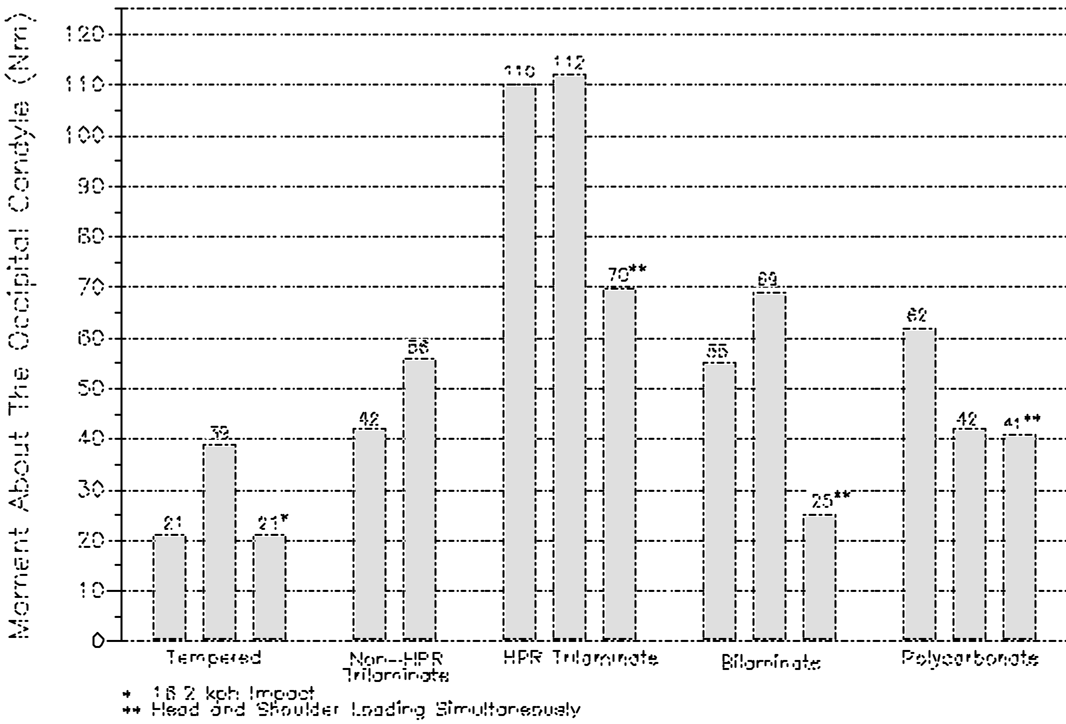

Figure 6.4 -- Moment About the Occipital Condyle Measurements

7.0 BENEFITS

This section updates agency estimates of the safety benefits of installing encapsulated advanced glazing in the front side windows of light vehicles. The initial benefit estimates and methodology were documented in the 1995 status report[1]. Therefore, this section does not repeat the statistical procedures and the systematic approach in detail. Only the updated benefit estimates are presented here. However, the revised benefits are presented here as ranges rather than point estimates. As stated in the 1995 status report, the occupant retention rates of glazing were derived from the NASS hard copy case review. A team of engineers reviewed and cross reviewed a sample of NASS ejection cases to ascertain the percentage of ejections that would be prevented by advanced glazing. A range of benefits is estimated to take into account the variation in estimates of retention effectiveness that result from this review process. One significant addition provided here is a sensitivity study to address the impact of increased belt use rate on glazing benefits.

The benefit estimates were updated by using newer CDS crash data and a minor modification to the estimation procedure. All the benefit estimates were calculated based on the police-reported KABCO* injury scale and then converted to the Abbreviated Injury Scale (AIS) classification scale** as used in CDS. The basic estimation procedure consisted of the following steps: (1) Establish baseline ejection population; i.e., the number of occupants ejected through closed or partially opened front side windows and in which advanced glazing would hold; (2) Estimate the number of fatalities and incapacitating injuries that would be prevented; (3) Redistribute the estimated fatal and incapacitating injuries that would be reduced to less serious injury levels; (4) Calculate the net benefits. The following is a detailed description of each step to estimate the upper bounds of the glazing benefits. The lower bounds of the benefits are derived using the same process, therefore are not repeated and only its final results are presented here.

7.1 Estimated Baseline Ejection Population

The baseline ejection population included all the ejections from front side windows of light vehicles with which glazing was either closed or partially opened before impact and the ejections would have potential to be prevented by advanced glazing. Data from the 1992-1996 NASS CDS were used to derive baseline fatalities and injuries. The most recent 5 years of data were used to reflect the change in safety belt usage and to reduce sampling variation. CDS-derived fatalities then were adjusted to the annualized level in the Fatalities Analysis Reporting System (FARS) for the same period to overcome the underestimation of fatalities in CDS.

The NASS hardcopy case review estimated that the proposed glazing systems could prevent ejection for 20 to 51 percent of all occupants ejected out of side windows annually. The following analysis in sections 7.1 through 7.3 will present the detailed results for only the 51% retention rate. The identical analysis was conducted at the 20 percent retention rate, however only the final results are summarized in the benefit discussion. For the 51 percent retention rate, Table 7.1 presents the estimated annual number of ejections

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*KABCO is the State police-reported injury severity. K = killed; A = incapacitating injury; B = nonincapacitating injury; C = possible Injury; O = no injury.

**Following are injury descriptors for the Abbreviated Injury Scale:
AIS 0 = no injury; AIS 1 = minor; AIS 2 = moderate; AIS 3 = serious; AIS 4 = severe; AIS 5 = critical

through front side windows of light vehicles in which windows were either closed or partially opened and the encapsulated advanced glazing would have remained in place. Data are shown by degree of ejection (complete or partial), seating position (driver or passenger), whether a safety belt was used, and injury severity by AIS system as used in CDS. The injury levels reported in the table are the maximum injury levels, or MAIS levels. As indicated, a total of 9,788 occupants ejected out front side windows were in vehicles in which it was deemed that advanced glazing would have remained in place during the crash had the vehicles been so equipped. Of the estimated 9,788 occupants whose ejections are estimated to be preventable, 6,875 were drivers, 2,913 passengers; 5,519 were completely ejected, 4,269 partially ejected; 2,097 (21 percent) were using a safety belt, 7,691 (79 percent) were not. A total of 1,800 (18 percent) of the ejected occupants were fatally injured; 2,260 incurred nonfatal serious injuries (MAIS 3-5); 5,724 incurred minor or moderate injuries (MAIS 1, 2); and 4 ejected occupants were uninjured.

7.2 Estimated Prevented Fatalities and Incapacitating Injuries

The next step was to estimate the number of fatalities and incapacitating injuries that would be prevented as the result of advanced glazing preventing ejection. These benefits were estimated based on the KABCO scale and converted to the AIS scale. As stated in the 1995 status report, the double-pair comparison method as original described by Evans (1986a, 1986b)[3,4] was used to derive the fatality reduction rate and injury mitigation rates. Also see Sikora (1986)[5] and Partyka (1993)[6] for relevant references. The double-pair comparison and related techniques to estimate the benefits when ejection is eliminated are described in the NHTSA's technical report "Estimating the Injury-Reducing Benefits of Ejection-Mitigating Glazing" (Winnicki, 1997)[7].

The following presentation illustrates how to estimate the reduction in fatal and incapacitating injuries for drivers who were partially ejected and who were not wearing seat belts. For ease of reference and comparison, the sequence of the illustration follows that recorded in the 1995 Status report. The injury distribution for such ejected occupants as presented in Table 7.1 is:

MAIS=0	0	
MAIS=1	1,227	
MAIS=2	350	
MAIS=3	126	
MAIS=4	48	
MAIS=5	20	
FATAL		367
TOTAL	2,138	

Table 7-1 – 1992-1996, Estimated Annual Number of Ejections Through Closed or Partially-Closed Front Side Windows of Light Vehicles for 51 Percent Occupant Retention Rate, by Degree of Ejection, Belt Use, Seat Position, Injury Severity

	Complete Ejections			Partial Ejections			Total Ejections		
	Restraint Usage			Restraint Usage			Restraint Usage		
	Yes	No	Total	Yes	No	Total	Yes	No	Total
Driver									
MAIS=0	0	4	4	0	0	0	0	4	4
MAIS=1	0	1,077	1,077	694	1,227	1,921	694	2,304	2,998
MAIS=2	61	747	808	223	350	573	284	1,097	1,381
MAIS=3	6	550	556	67	126	193	73	676	749
MAIS=4	0	97	97	19	48	67	19	145	164
MAIS=5	0	114	114	32	20	52	32	134	166
FATAL*	3	779	782	264	367	631	267	1,146	1,413
TOTAL	70	3,368	3,438	1,299	2,138	3,437	1,369	5,506	6,875
Passenger									
MAIS=0	0	0	0	0	0	0	0	0	0
MAIS=1	0	397	397	371	36	407	371	433	804
MAIS=2	0	274	274	249	18	267	249	292	541
MAIS=3	73	683	756	1	33	34	74	716	790
MAIS=4	0	370	370	0	6	6	0	376	376
MAIS=5	0	15	15	0	0	0	0	15	15
FATAL*	14	255	269	20	98	118	34	353	387
TOTAL	87	1,994	2,081	641	191	832	728	2,185	2,913
Driver & Passenger									
MAIS=0	0	4	4	0	0	0	0	4	4
MAIS=1	0	1,474	1,474	1,065	1,263	2,328	1,065	2,737	3,802
MAIS=2	61	1,021	1,082	472	368	840	533	1,389	1,922
MAIS=3	79	1,233	1,312	68	159	227	147	1,392	1,539
MAIS=4	0	467	467	19	54	73	19	521	540
MAIS=5	0	129	129	32	20	52	32	149	181
FATAL*	17	1,034	1,051	284	465	749	301	1,499	1,800
TOTAL	157	5,362	5,519	1,940	2,329	4,269	2,097	7,691	9,788

* Fatalities derived from 1992-1996 NASS CDS were adjusted to the annualized level at the same period reported in FARS.

In the previous analysis, the matched-pair estimate of the increase in risk of fatality of being partially ejected for unrestrained occupants was 3.4768. It follows that the reduction in the risk of fatality from preventing ejection is 1-1/3.4768 or 0.7124. The reduction in fatalities was therefore estimated to be 0.7124 X 367 = 261 fatalities prevented. (The redistribution of these prevented fatalities to lower injury levels is presented in the next section.)

The increase in risk of incapacitating injury of being partially ejected for unrestrained occupants was estimated to be 2.3117. The reduction in incapacitating injury from preventing ejection was 1-1/2.3117 or 0.5674. As in estimating the fatality reduction, the next step was to multiply the number of "A" (incapacitating) injuries by this fraction to estimate the reduction in these injuries. First, however, the above tabulation of injuries rated by the MAIS scale was converted to its KABCO equivalent to obtain the estimated number of incapacitating ("A") injuries to which to apply the reduction factor. The conversion factors used here were slightly different from those in the 1995 Status report. In this report, fatalities were adjusted directly to the FARS level; therefore, fatal injuries were converted only to "K"-killed in KABCO system. Also, to keep the fatality count constant, the MAIS 0-5 injuries were converted only to non-"K" injuries. Thus, Part 2 and Part 3 of Table 7.2 are the adjusted converting factors. Using the conversion factors, except for fatalities, in Part 2 of Table 7.2, the injury distribution of drivers who were not wearing seat belts and were partially ejected was converted from the MAIS system to the KABCO system:

MAIS Injury Distribution		**KABCO Injury Distribution**	
MAIS=0	0	A	336
MAIS=1	1227	B	495
MAIS=2	350	C	502
MAIS=3	126	K	106
MAIS=4	48	NO	403
MAIS=5	20	ISU	23
FATAL*	106	UNK	12
TOTAL	1877	TOTAL	1877

*Excludes 261 prevented fatalities

As indicated above, conversion of the MAIS injury distribution to the KABCO system produced an estimated 336 incapacitating ("A") injuries. The 336 "A" injuries were multiplied by the corresponding injury reduction factor of 0.5674 derived using the matched-pair procedure to estimate the number of incapacitating injuries occurring to partially ejected unbelted drivers that would be prevented as the result of drivers being retained inside their vehicles because of advanced glazing. The estimate of incapacitating injuries prevented would be 0.5674 X 336 = 191.

Table 7.2 – KABCO/MAIS Injury Rating Systems

Part 1 – KABCO/MAIS Injury Distribution Table - 1982-1986 NASS CDS Injuries

MAIS	A	B	C	K	NO	ISU	UNK
0	34125	251763	1313849	2243	55920352	16197	567577
1	1106880	4039582	4731293	2899	4493704	151977	111255
2	628338	636692	445949	1188	125755	33822	11258
3	376136	153411	99524	238	17347	9352	5431
4	65427	13620	4229	394	716	3688	139
5	39650	3518	1219	0.00	0.00	288	310
FATAL	12194	1350	645	168780	60	819	0.00
TOTAL	2262750	5099936	6596708	175742	60557934	216143	695970

A = Incapacitating injury
B = Nonincapacitating injury
C = Possible injury
K = killed

No = No injury
ISU = Injured, but severity unknown
UNK = Unknown if injured

MAIS 0 = No injury
MAIS 1 = Minor
MAIS 2 = Moderate
MAIS 3 = Serious

MAIS 4 = Severe
MAIS 5 = Critical
AIS = Abbreviated Injury Scale
MAIS = Maximum AIS

Part 2 – Adjusted* MAIS To KABCO Conversion Table - 1982-1986 NASS CDS Injuries

MAIS	A	B	C	K	NO	ISU	UNK	TOTAL
0	0.00059	0.00433	0.02261	0.00000	0.96242	0.00028	0.00977	1.00000
1	0.07564	0.27603	0.32329	0.00000	0.30706	0.01038	0.00760	1.00000
2	0.33390	0.33834	0.23698	0.00000	0.06682	0.01797	0.00598	0.99999
3	0.56886	0.23202	0.15052	0.00000	0.02624	0.01414	0.00821	0.99999
4	0.74501	0.15509	0.04815	0.00000	0.00816	0.04200	0.00159	1.00000
5	0.88141	0.07820	0.02710	0.00000	0.00000	0.00640	0.00689	1.00000
FATAL	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000	1.00000

* Fatalities were converted only to "K" injuries in KABCO system.
MAIS 0-5 injuries were converted to non-"K" injuries in KABCO system.

Part 3 – Adjusted* KABCO To MAIS Conversion Table - 1982-1986 NASS CDS Injuries

MAIS	A	B	C	K	NO	ISU	UNK
0	0.01516	0.04938	0.19919	0.00000	0.92423	0.07523	0.81551
1	0.49183	0.79229	0.71729	0.00000	0.07342	0.70581	0.15986
2	0.27920	0.12487	0.06761	0.00000	0.00206	0.15708	0.01618
3	0.16713	0.03009	0.01509	0.00000	0.00029	0.04343	0.00780
4	0.02907	0.00267	0.00064	0.00000	0.00001	0.01712	0.00020
5	0.01762	0.00069	0.00018	0.00000	0.00000	0.00134	0.00045
FATAL	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000
TOTAL	1.00001	0.99999	1.00000	1.00000	1.00001	1.00001	1.00000

* "K" injuries in KABCO system were converted only to fatalities.
Non-"K" injuries in KABCO system were converted to MAIS 0-5 injuries.

Estimates of fatal and incapacitating injury reduction for the other breakouts in Table 7.1 -- restrained drivers partially ejected, restrained and unrestrained passengers partially ejected, and unrestrained drivers and passengers completely ejected -- were similarly derived. Table 7.3 presents the fatality and incapacitating injury reduction factors derived employing the matched-pair technique and the number of fatalities and incapacitating injuries that would be prevented for the breakouts in Table 7.1.

Table 7.3 – Reduction in the Risk of Fatal and Incapacitating Injury from Preventing Ejection, 51 Percent Occupant Retention Rate

Occupant Category	Increased Risk if Ejected (X)[1]		Reduction in Risk (1-1/X)[1]		Estimated Fatalities Prevented	Estimated Incapacitating ("A") Injuries Prevented
	Of Fatality	Of Incapacitating Injury	Of Fatality	Of Incapacitating Injury		
Driver, Complete Ejected, No restraint	3.3945 (0.9369)*	1.8759 (0.4744)*	0.7054 (0.0813)*	0.4669 (0.1348)*	550	381
Passenger, Complete Ejected, No restraint	3.1441 (0.8626)*	1.6447 (0.4178)*	0.6819 (0.0873)*	0.3920 (0.1544)*	174	312
Driver, Partially Ejected, Restraint	3.4491 (1.1167)*	1.9287 (0.5169)*	0.7101 (0.0939)*	0.4815 (0.1389)*	187	99
Driver, Partially Ejected, No Restraint	3.4768 (0.8255)*	2.3117 (0.5300)*	0.7124 (0.0683)*	0.5674 (0.0992)*	261	191
Passenger, Partially Ejected, Restraint	3.3291 (1.0813)*	1.6891 (0.4513)*	0.6996 (0.0976)*	0.4080 (0.1582)*	14	46
Passenger, Partially Ejected, No Restraint	3.1186 (0.7403)*	1.8890 (0.4334)*	0.6793 (0.0761)*	0.4706 (0.1215)*	67	15
Total Injuries and Fatalities Prevented					1,253	1,044

1. Adapted from the 1995 Status report
* Standard error estimate

7.3 Redistribution of Prevented Estimated Fatal and Incapacitating Injuries

The next step in evaluating the potential benefits of advanced glazing was to redistribute the fatal and incapacitating injuries that would be prevented by preventing ejection to less serious injury levels. It was assumed that the effect of ejection prevention by the advanced glazing is the same as the effect of being prevented from ejection by other elements of the vehicle interior. Thus, the distribution of injuries among non-ejected occupants of motor vehicles in accidents involving ejections was used as an estimate of the distribution of injuries among non-ejected occupants when the advanced glazing is in place. Again, an illustration of the estimation procedure is provided using data for drivers who were partially ejected and not wearing seat belts, as reported in Table 7.1.

First, the redistribution to lower injury levels of the estimated 261 fatalities that would be prevented for this category of ejection was estimated. This entailed calculation of the States' injury distribution (using the KABCO rating system) for drivers who were not ejected in crashes in which passengers not wearing restraints were partially ejected, as discussed above. The prevented fatalities were redistributed according to this KABCO distribution and then converted to the MAIS injury scale. This procedure is shown below in Table 7.4.

Table 7.4 – Redistribution of 261 Fatalities to Partially Ejected, Unrestrained Drivers That Would Be Prevented to Lesser Injury Levels* For 51 Percent Occupant Retention Rate

Fatalities Prevented	States' Injury Dist. for Surviving Unejected Drivers in Comparable Crashes	Percent of Group	Redistribution Fatalities by KABCO	Converted to MAIS Injury Scale MAIS	Redistributed Fatalities
261	A	0.2755	72	0	51
	B	0.4079	106	1	154
	C	0.1690	44	2	36
	No Injury	0.1476	39	3	16
	Total	1.0000	261	4	2
				5	2
				Total	261

* An estimated 261 fatal injuries to unrestrained drivers who were partially ejected would be prevented by advanced glazing. The redistribution of these 261 fatalities to lesser injury levels is presented as an illustration of the procedure employed in redistributing to lesser injury levels all fatalities that it was estimated would be prevented.

Similarly, the "A" level (incapacitating) injuries estimated to be prevented by advanced glazing were redistributed to levels "B", "C", and " No Injury" under the State police rating systems. The procedure for redistributing the estimated 191 "A" level injuries that would be prevented by preventing partial ejections of restrained drivers is shown in Table 7.5. As in Table 7.4, the estimated reduction in injury based on the KABCO distribution was converted to the MAIS scale.

Table 7.5 – Redistribution of 191 Serious Injuries to Partially Ejected, Unrestrained Drivers That Would Be Prevented to Lesser Injury Levels* for 51 Percent Occupant Retention Rate

Incapacitating Injuries Prevented	States' Distribution of lesser Injury for Drivers in Comparable Crashes	Percent of Group	Redistributed Incapacitating Injuries by KABCO	MAIS Injury Scale	Redistributed Incapacitating Injuries by MAIS Scale
191	B	0.5630	108	0	50
	C	0.2332	45	1	121
	No Injury	0.2038	38	2	16
	Total	1.0000	191	3	4
				4	0
				5	0
				Total	191

* An estimated 191 incapacitating ("A" level) injuries to unrestrained drivers who were partially ejected would be prevented by advanced glazing. The redistribution of these 191 injuries to lesser injury levels is presented as an illustration of the procedure employed in redistributing to lesser injury levels all serious injuries that it was estimated would be prevented.

Further, as an illustration of the methodology employed for estimating safety benefits for the driver vs. passenger, degree of ejection, and restraint usage breakdowns presented in Table 7.1, Table 7.6 below presents the calculation of the estimated new injury distribution that partially ejected, unrestrained drivers would experience if advanced glazing prevented their ejection. As indicated, the estimation began with the present injury distribution (as reported in Table 7.1) and (1) deducted the fatalities that would be prevented, (2) added the nonfatal injuries that the previously fatally injured drivers would incur (as presented in Table 7.4), (3) deducted incapacitating ("A") injuries that would be prevented, and (4) added lesser level injuries that drivers who had sustained the serious injuries would incur instead (as presented in Table 7.5).

Table 7.6 – Partially Ejected, Unrestrained Drivers - Estimated Number of Fatal and Serious Injuries Prevented and Their Redistribution to Lesser Injury Severity Levels for 51 Percent Occupant Retention Rate

MAIS	Present Injury Distribution	Less Fatalities Prevented	Plus Redist. Prevented Fatalities	Less "A" Injuries Prevented*	Plus Redist. "A" Inj.	Est. New Injury Dist. with Ejections Prevented
0	0		51	0	50	101
1	1,227		154	53	121	1,449
2	350		36	66	16	336
3	126		16	41	4	105
4	48		2	20	0	30
5	20		2	11	0	11
Fatal	367	261	0	0	0	106
Total	2,138		261	191	191	2,138

* Data in Table 7.5 were used to distribute the estimated 191incapacitating injuries that would be prevented by the MAIS rating system.

The same procedure as presented above in estimating injury reduction for unrestrained drivers who were partially ejected was used in estimating safety benefits for the other breakouts of ejected occupants reported in Table 7.1. Table 7.7 shows the present injury distribution, the estimated new injury distribution reflecting the redistribution of fatalities and incapacitating injuries that would be reduced to lower injury levels, and the differences between the two distributions, which are the estimated safety benefits.

The last part of Table 7.7 shows the estimated injury distribution for all ejected occupants before and after the installation of advanced glazing and the difference in these distributions. As reported, the estimated change in the injury distribution would be as follows (note the signs have been changed so the direction of change will be more readily understood when the data are presented alone):

MAIS	Change in Injury Levels
0	519
1	1,259
2	-27
3	-271
4	-158
5	-69
Fatal	-1,253
Total	0

There could be possible disbenefits to advanced glazing that were not accounted for thus far in the analysis. Such disbenefits may include potential increases in head/neck injuries due to contact and additional lacerations with advanced glazing materials that may remain in place (as opposed to current tempered glass which readily shatters upon impact). Based on the FMH tests discussed in Section 5, the advanced glazing did not necessarily produce higher HIC responses than the tempered glass windows currently in use. Thus, the advanced glazing would not be expected to increase head injuries. The report does not yet address neck injury because lateral neck criteria have not been completed. However, even if there can be small increases in low level neck injury, it is anticipated that the fatality prevention benefit of advanced glazing would likely greatly outweigh any such disbenefits.

Table 7.7 – Estimated Safety Benefits of Advanced Glazing, Segregated by Driver vs. Passenger, Degree of Ejection, and Restraint Usage for 51 Percent Occupant Retention Rate

	MAIS	Present Injury Distribution	Est. Injury Distribution with Ejection Prevented	Difference = Safety Benefits
Driver Completely Ejected, Unrestrained	0	4	212	-208
	1	1,077	1,604	-527
	2	747	741	6
	3	550	444	106
	4	97	68	29
	5	114	70	44
	Fatal	779	229	550
	Total	3,368	3,368	0
	MAIS	**Present Injury Distribution**	**Est. Injury Distribution with Ejection Prevented**	**Difference = Safety Benefits**
Passenger Completely Ejected, Unrestrained	0	0	118	-118
	1	397	685	-288
	2	274	289	-15
	3	683	546	137
	4	370	264	106
	5	15	11	4
	Fatal	255	81	174
	Total	1,994	1,994	0
	MAIS	**Present Injury Distribution**	**Est. Injury Distribution with Ejection Prevented**	**Difference = Safety Benefits**
Driver Partially Ejected, Restrained	0	0	63	-63
	1	694	841	-147
	2	223	222	1
	3	67	62	5
	4	19	14	5
	5	32	20	12
	Fatal	264	77	187
	Total	1,299	1,299	0
	MAIS	**Present Injury Distribution**	**Est. Injury Distribution with Ejection Prevented**	**Difference = Safety Benefits**
Driver Partially Ejected, Unrestrained	0	0	101	-101
	1	1,227	1,449	-222
	2	350	336	14
	3	126	105	21
	4	48	30	18
	5	20	11	9
	Fatal	367	106	261
	Total	2,138	2,138	0

Table 7.7 – Estimated Safety Benefits of Advanced Glazing, Segregated by Driver vs. Passenger, Degree of Ejection, and Restraint Usage for 51 Percent Occupant Retention Rate (Continued)

	MAIS	Present Injury Distribution	Est. Injury Distribution with Ejection Prevented	Difference = Safety Benefits
Passenger Partially Ejected, Restrained	0	0	13	-13
	1	371	398	-27
	2	249	221	28
	3	1	3	-2
	4	0	0	0
	5	0	0	0
	Fatal	20	6	14
	Total	641	641	0

	MAIS	Present Injury Distribution	Est. Injury Distribution with Ejection Prevented	Difference = Safety Benefits
Passenger Partially Ejected, Unrestrained	0	0	16	-16
	1	36	84	-48
	2	18	25	-7
	3	33	29	4
	4	6	6	0
	5	0	0	0
	Fatal	98	31	67
	Total	191	191	0

	MAIS	Present Injury Distribution*	Est. Injury Distribution with Ejection Prevented	Difference = Net Safety Benefits
All Ejection Categories	0	4	523	-519
	1	3,802	5,061	-1,259
	2	1,861	1,834	27
	3	1,460	1,189	271
	4	540	382	158
	5	181	112	69
	Fatal	1,783	530	1,253
	Total	9,631	9,631	0

* The injury distributions for completely ejected restrained drivers and passengers, as reported in Table 7.1, are not included in this table. Those ejected were using shoulder belts only (with two exceptions); such restraints will not be permitted beginning with the 1998 passenger car and 1999 light truck model year fleets. It is assumed that these occupants would wear lap shoulder belts in the future and not be ejected. Ejection prevention would be attributable to restraint usage, not advanced glazing.

Tables 7.1 through 7.7 present the benefits procedure and detailed results for the 51 percent occupant retention rate. The same procedure was used to compute the benefits for the 20 percent occupant retention rate but are not shown. Summarizing these results, an estimated 501 to 1,253 fatalities and 418 to 1,044 incapacitating ("A") injuries could be prevented by installing advanced glazing in the front side windows of light vehicles. As estimated, the redistribution of these prevented fatalities and incapacitating injuries could result in the following net safety benefits: A range from 501 to 1,253 fewer fatalities, 199 to 498 fewer serious (MAIS 3-5) injuries, and 11 to 27 fewer moderate (MAIS 2) injuries. In addition, 208 to 519 presently injured, ejected occupants could potentially be uninjured as the result of their being retained inside their vehicles by advanced glazing. The number of cases in which a minor injury (MAIS 1) was the most severe injury could increase from 504 to 1,259. Benefits would be expected to greatly exceed any disbenefits for both the 20 and 51 percent occupant retention rates.

7.4 Sensitivity Study

This section estimates the change in benefits that could result from increased safety belt use. Based on a compilation of state surveys from 1992 through 1996, the average national belt usage rate in that period was 66.2 (base year usage rate) percent*. To give a general understanding of the scope of the changes in benefits, this report examines benefits of advanced glazing at three increased belt usage rates: 71.2, 76.2, and 81.2 percent, which correspond to 5, 10 and 15 percentage point increases over the base rate. For each increased belt use rate, the analysis first needed to adjust the baseline ejection population to reflect the impact of increased belt use. These new baseline ejections (**adjusted baseline population**) are illustrated for the 51 percent occupant retention rate and are equivalent to those listed in Table. Then, the procedure was applied as stated in previous sections, to derive the new net benefit of advanced glazing at that specific belt use level. The 51 percent occupant retention is used to illustrate the estimation procedure in sections 7.4.1 through 7.4.2. The same processes were used to estimate the change in benefits for the 20 percent occupant retention rate. Again, only the final results are summarized in the benefit discussion.

7.4.1 Estimated Adjusted Baseline Population

To derive the adjusted baseline population, it was first necessary to determine what portion of baseline population ejections would actually be prevented by increased safety belt use. This portion is called the incremental benefits. NHTSA's belt usage software (BELTUSE) program** (Blincoe, 1994)[8] was used to derive these incremental benefits. The software requires the input of baseline injuries, base year belt usage rate (66.2 percent), and the new increased belt usage rates (e.g, 71.2, 76.2, and 81.2 percent) to calculate the incremental safety benefits. The software assumes that safety belts impact only front-outboard occupants ages 5 and older. Thus, the number of annualized front-outboard occupants of age 5 or greater was derived

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*U.S. national safety belt use rates from state surveys: 62%-1992, 66%-1993, 67%-1994, 68%-1995, and 68%-1996.

*PC-DOS based software. The program also can be ran under the Microsoft Window environment.

from 1992 to 1996 CDS and used as the baseline injuries. CDS-derived fatalities were adjusted to the 1992-1996 FARS average. Table 7.8 shows the baseline injuries by MAIS level and ejection type. Note that all the MAIS 7 injuries (representing cases where injury severity was unknown) were included in the MAIS 1 injuries. This practice underestimated the MAIS 2 to MAIS 5 benefits. However, this underestimate had little effect on the overall results.

Table 7.8 -- Front-Outboard Occupants, Age 5 and Older by Ejection Type

MAIS	No Ejection	Completed Ejection	Partial Ejection	Total
0	1,951,179	557	641	1,952,377
1	1,655,058	11,673	7,738	1,674,469
2	171,111	6,337	3,739	181,187
3	56,136	3,828	2,795	62,759
4	9,732	1,574	446	11,752
5	3,754	499	316	4,569
6	17	0	0	17
Fatal	21,388	6,077	3,299	30,764
Total	3,868,375	30,545	18,974	3,917,894

After inputting the baseline numbers as shown in Table 7.8 and the belt usage rates (baseline and new rates), the BELTUSE software estimated the reductions in fatalities, MAIS 2-5 injuries, and MAIS 1 injuries. The software did not provide a separate estimate for each MAIS 2-5 level. But, it assumed a weighted effectiveness of 53.7 percent (depending on the passenger car and light truck ratio) against all MAIS 2-5 injuries. Therefore, the analysis estimated the benefits for individual MAIS levels by assuming the safety benefit distribution was the same as that of the baseline population. Table 7.9 shows the incremental safety benefits that would be achieved by increasing the belt usage rate by 5, 10 and 15 percentage points. These incremental benefits included those accrued by preventing ejection as well as those from crashes without ejection involvements.

Table 7.9 -- Lives Saved and Injuries Reduction by Increased Belt Use for 51 Percent Occupant Retention Rate

MAIS	Belt Use Increase by		
	5%	10%	15%
1	8,966	17,937	26,866
2	7,620	15,241	22,862
3	2,640	5,279	7,919
4	494	989	1,483
5	193	386	579
Fatal	1,227	2,507	3,839
Total	21,140	42,339	63,548

These benefits included all injury reduction from safety belt use regardless of whether the ejection prevention was a contributing factor. So, the next step was to estimate the portion for which ejection was prevented while the advanced glazing remained intact. This portion was deducted from the initial baseline (i.e., ejections in Table 7.1) to derive the adjusted baseline. The BELTUSE software did not estimate safety belt benefits by ejection status. Instead, the impact of belt use on ejection was derived based on the proportion of the population that was ejected and the fraction of those cases where advanced glazing would have remained intact during the crashes. As shown in Table 7.8, about 30.5 percent of the fatalities were ejected. If the safety belt usage increased from 66.2 to 71.2 (a 5 percentage point increase), for example, about 374 (=1,227 x 0.305) fatalities would be prevented due to ejection elimination. Table 7.10 shows the total lives saved and injuries reduced by MAIS level because of an increase in belt use resulting in prevention of ejections.

Table 7.10 -- Lives Saved Through Ejection Elimination as a Result of Increased Belt Use for 51 Percent Occupant Retention Rate

MAIS	Belt Use Increase		
	5%	10%	15%
1	107	215	322
2	424	848	1,271
3	279	557	836
4	85	170	255
5	34	69	103
Fatal	374	764	1,170
Total	1,303	2,623	3,957

If advanced glazing had been installed, about 51 percent (section 7.1) of these safety benefits would be those where advanced glazing had remained in place. This means that 191 (=374 x 0.51) of the 374 fatalities were prevented when the advanced glazing would have remained. Table 7.11 represents the portion (i.e., less benefits for glazing) of the safety benefits by three belt usage levels.

The difference between the baseline population (Table 7.1) and the safety belt impacts (Table 7.11) is the adjusted baseline population. Table 7.12 shows the adjusted baseline ejection population for the belt usage rate of 71.2 percent (a 5 percentage point increase).

Table 7.11 -- Estimated Benefits Through Ejection Elimination as a Result of Increased Belt Use for 51 Percent Occupant Retention Rate

MAIS	Belt Use Increase		
	5%	10%	15%
1	55	110	164
2	216	432	648
3	142	284	426
4	43	87	130
5	17	35	53
Fatal	191	390	597
Total	664	1,338	2,018

Table 7.12 – Estimated Annual Number of Ejections Through front Side Windows of Light Vehicles for 51 Percent Occupant Retention Rate, 71.2 Percent Belt Usage Rate (Adjusted for a 5 Percentage Point Increase)

MAIS	Original Injury Distribution (Initial Baseline)	Safety Belt Benefits	Adjusted Injury Distribution (Adjusted Baseline)
0	4	0	4
1	3,802	55	3,747
2	1,861	216	1,645
3	1,460	142	1,318
4	540	43	497
5	181	17	164
Fatal	1,783	191	1,592
Total	9,631	664	8,967

7.4.2 Estimated Adjusted Benefits of Advanced Glazing

The benefits estimate procedure documented in the previous sections was applied here to estimate adjusted benefits. However, adjusted benefits were estimated as in the overall ejection population regardless of ejection status and occupant type. In this sense, weighted reduction rates in fatalities and incapacitating injury from prevention of ejection were calculated to assess the overall glazing benefits. As shown in Table 7.13, prevention of ejection would reduce the risk of occupant fatality by 70.3 percent, and of incapacitating injury by 45.4 percent. Note that the weights were the proportion of overall incidents.

Table 7.14 lists the estimated benefits for advanced glazing after adjusting for belt use. The advanced glazing would prevent from 1,119 fatalities and 952 incapacitating injuries if the belt use rate was at 71.2 percent, 979 fatalities and 860 incapacitating injuries at 76.2 percent, and 833 fatalities and 765 incapacitating injuries at 81.2 percent. If the belt use rate increased 5 percentage points from the current rate to 71.2 percent, glazing benefits would be reduced by 11 percent. For a 15 percentage point increase to 81.2 percent, glazing benefits would be reduced by 34 percent. Table 7.15 shows the same data assuming a 20 percent occupant retention rate. The effect of increasing belt usage is proportionally the same at the lower occupant retention rate.

Table 7.13 - Reduction in Fatality and Incapacitating Injury Rates from Ejection Prevention at 51 Percent Occupant Retention Rate

Person Type/Ejection Type/Restraint	Fatality			Incapacitating ("A") Injury		
	Estimated Reduction in Risk	Weights	Weighted Reduction in Risk	Estimated Reduction in Risk	Weights	Weighted Reduction in Risk
Driver, Complete Ejection, No Restraint	0.7054	0.44	0.3082	0.4669	0.35	0.1657
Passenger, Complete Ejection, No Restraint	0.6819	0.14	0.0975	0.3920	0.35	0.1358
Driver, Partial Ejection, Restraint	0.7101	0.15	0.1051	0.4815	0.09	0.0432
Driver, Partial Ejection, No Restraint	0.7124	0.21	0.1466	0.5674	0.15	0.0830
Passenger, Partial Ejection, Restraint	0.6996	0.01	0.0078	0.4080	0.05	0.0199
Passenger, Partial Ejection, No Restraint	0.6793	0.05	0.0373	0.4706	0.01	0.0066
All Ejections		1.00	**0.7027**		1.00	**0.4541**

Table 7.14 -- Estimated Safety Benefits of Advanced Glazing
Adjusted for Safety Belt Use Increase by 5, 10, and 15 Percentage Points
for 51 Percent Occupant Retention Rate

MAIS	Adjusted Baseline	Fatalities Prevented	Redistri-bution of Fatalities	"A" Injuries Prevented	Redistri-bution of "A" Injuries	Injury Distribution With Ejection Prevented	Adjusted Net Benefits	Baseline Net Benefits*	Baseline Less Adjusted Net Benefits
At 71.2 Percent Belt Usage Level - a 5 Percentage Point Increase									
0	4		218	0	250	472	-468	-519	-51
1	3,747		662	129	600	4,880	-1,133	-1,259	-126
2	1,645		156	249	82	1,634	11	27	16
3	1,318		68	340	19	1,065	253	271	18
4	497		10	168	1	340	157	158	1
5	164		5	66	0	103	61	69	8
Fatal	1,592	1,119				473	1,119	1,253	134
Total	8,967		1,119	952	952	8,967			
At 76.2 Percent Belt Usage Level - a 10 Percentage Point Increase									
0	4		191	0	226	421	-417	-519	-102
1	3,692		579	127	541	4,685	-993	-1,259	-266
2	1,429		136	217	74	1,422	7	27	20
3	1,176		59	304	18	949	227	271	44
4	453		9	153	1	310	143	158	15
5	146		5	59	0	92	54	69	15
Fatal	1,393	979				414	979	1,253	274
Total	8,293		979	860	860	8,293			
At 81.2 Percent belt Usage Level - a 15 Percentage Point Increase									
0	4		162	0	200	366	-362	-519	-157
1	3,638		493	125	482	4,488	-850	-1,259	-409
2	1,213		116	184	66	1,211	2	27	25
3	1,034		50	267	16	833	201	271	70
4	410		8	138	1	281	129	158	29
5	128		4	51	0	81	47	69	22
Fatal	1,186	833				353	833	1,253	420
Total	7,613		833	765	765	7,613			

Benefits at 66.2 percent of belt usage rate

Table 7.15 -- Estimated Safety Benefits of Advanced Glazing
Adjusted for Safety Belt Use Increase by 5, 10, and 15 Percentage Points
for 20 Percent Occupant Retention Rate

MAIS	Adjusted Baseline	Fatalities Prevented	Redistribution of Fatalities	"A" Injuries Prevented	Redistribution of "A" Injuries	Injury Distribution With Ejection Prevented	Adjusted Net Benefits	Baseline Net Benefits*	Baseline Less Adjusted Net Benefits
At 71.2 Percent Belt Usage Level - a 5 Percentage Point Increase									
0	0		87	0	100	187	-187	-208	-21
1	1,499		265	52	240	1,952	-453	-504	-51
2	658		63	100	33	654	4	11	7
3	527		28	136	8	427	100	108	8
4	199		4	67	0	136	63	63	0
5	66		1	26	0	41	24	28	4
Fatal	637	448				189	448	501	53
Total	3,586		448	381	381	3,586			
At 76.2 Percent Belt Usage Level - a 10 Percentage Point Increase									
0	2		76	0	90	168	-166	-208	-42
1	1,477		232	51	217	1,875	-398	-504	-106
2	572		54	87	30	569	3	11	8
3	470		24	122	7	379	91	108	17
4	181		4	61	0	124	57	63	6
5	58		2	23	0	37	21	28	5
Fatal	557	392				165	392	501	109
Total	3,317		392	344	344				
						3,317			
At 81.2 Percent belt Usage Level - a 15 Percentage Point Increase									
0	2		65	0	80	147	-145	-208	-157
1	1,455		197	50	193	1,795	-340	-504	-164
2	485		46	74	26	483	2	11	9
3	414		20	107	7	334	80	108	28
4	164		3	55	0	112	52	63	11
5	51		2	20	0	33	18	28	10
Fatal	474	333				141	333	501	168
Total	3,045		333	306	306	7,613			

Benefits at 66.2 percent of belt usage rate

8. 0 COST

This section evaluates the cost of the proposed advanced glazing systems. The incremental costs estimated in the 1995 status report, between $48 and $79 per vehicle to modify the two front side windows are used here. This cost estimate was developed for vehicles with framed windows only and reflects the prototype design used in the 1995 status report. This cost figure was not updated to reflect the prototype designs developed in this report. To obtain a rough estimate of the annual consumer cost of installing advanced glazing in the front side windows of the light vehicle fleet, it was assumed that the costs for a 1995 Ford Taurus would be the average cost for all light vehicles. Further, it was estimated that annual sales of new cars and light trucks would total 16 million units (8.0 million passenger cars and 8.0 million light trucks; approximate trend projection detail, Table 6, "Review of the U.S. Economy, Long-Range Focus," Summer 1998)[9] in the year 2005-2006 time frame when any requirement for advanced glazing might be implemented. As presented in column 3 of Table 8.1, the estimated annual consumer cost of installing advanced glazing in the front side windows of new light vehicles would range from $768,000,000 to $1,270,000,000, depending on the type of glazing installed. Note that the report uses uninflated 1995 costs because the research team believes the estimated price of installing advanced glazing in 1997 dollar value would be very similar to that in 1995 dollar value due to low inflation, material technology advancement, and manufacturer process improvement. The projected leadtime estimated by Management Engineering Associates (MEA) in 1995 for phase-in of advanced glazing for new vehicles was about 3 years. The final research status report will update the costs, weight analysis, leadtime, and incremental capital equipment estimates.

Table 8.1 – Estimated Incremental Cost for Ejection Mitigating Glazing Installed in Front Side Windows

Type of Advanced Glazing	Estimated Consumer per Vehicle Cost of Advanced Glazing in Front Side Windows	Estimated Annual Consumer Cost of Installing Advanced Glazing in New Light Vehicles*
Trilayer Glass	$48.00	$768,000,000
Dupont "Sentry Glas"	$50.50	$808,000,000
St Gobain Bilayer	$51.34	$821,440,000
Rigid Plastic	$79.38	$1,270,080,000

* The estimates are based on light vehicle annual sales of 16 million units in the 2005-2006 timeframe.

The cost of advanced glazing would be incurred by consumers at the time of vehicle purchase in the form of higher sales prices. On the other hand, the ejection mitigation benefits of advanced glazing would accrue over the operating lives of the vehicles they purchase. The benefits realized would be confined to safety benefits; advanced glazing and other "crashworthiness" technologies do not provide vehicle property damage or other categories of savings associated with crashes being prevented, as do "crash avoidance" technologies, such as advanced brake systems, center high mounted stop lamps, and vehicle modifications that improve driver visibility. Vehicles equipped with advanced glazing would still be heavily damaged in ejection-producing collisions, and property damage loss and the expense associated with congestion, police investigation, and site cleanup would still exist.

9.0 SUMMARY

The following is a summary of the research and findings presented in this report:

In conjunction with Pilkington/Libbey-Owens-Ford, four types of advanced glazings were identified for evaluation in this research program. These were a non-HPR trilaminate, an HPR trilaminate, a bilaminate, and a polycarbonate (rigid plastic). The General Motors C/K Pickup side door window was selected as the platform for this work, since the production version already included encapsulated vertical edges. In order to provide ejection mitigation capabilities, this encapsulation design was modified to incorporate a urethane T-edge on the vertical edges of the window. The corresponding vertical edges of the door window frame were also modified, by creating a C-channel to secure the T-edge, which maintained the window's ability to be raised and lowered. Through testing, it was found that modification of the top and diagonal edges of the window and corresponding door window frame was also necessary to provide adequate retention. Modifications to the top and diagonal edges of the window and the energy transfer through them, make this proposed design not applicable to vehicles with frameless windows.

A series of tests was conducted to refine the encapsulation/door window frame designs and to evaluate the retention capability of the various advanced glazings. The retention capability was assessed based on the glazing systems' capability to retain a guided, 18 kg (40 lb) impactor moving at 24 kmph (15 mph). To achieve retention at this severity, it was necessary to modify the top and diagonal edges of the door window frame by adding sheet metal to simulate a U-channel. It was found that a U-channel depth of 38 mm (1½") was required. An additional 25 mm (1") reinforcement was required at the transition point between the top and diagonal edges. In addition to the T-edge encapsulation on the vertical edges of the glazings, it was also necessary to modify the top and diagonal edges. This was done using a urethane, non-T-edge encapsulation and/or by bonding a polycarbonate strip (either 38 mm or 76 mm wide) to those edges. These door frame modifications were developed to achieve occupant retention at the upper end of the proposed test speeds. A lower impact speed may require fewer modifications to achieve this goal. Using a lower speed may make it more feasible to develop prototype systems for vehicles with frameless windows.

Using these glazing and door window frame modifications, it was found that the bilaminate, HPR trilaminate, and the polycarbonate side glazing systems were capable of containing impacts from an 18 kg impactor at a speed of 24 kmph. The non-HPR trilaminate glazing did not have sufficient strength to absorb this level of impact. Based on the tests using the best performing top and diagonal edge modification, the following results were obtained:

- When impacted at the center window location, the bilaminate glazing (with 76 mm polycarbonate strip on top/diagonal edges) produced 100 percent containment without tearing of the plastic layer, and with 127 to 157 mm (5.0 to 6.2") of deflection. When impacted at the upper rear corner location, this same glazing (with urethane top/diagonal edges) produced 75 percent containment without tearing of the plastic layer, and with 186 mm (7.3") of deflection.

- When impacted at the center window location, the HPR trilaminate glazing (with 38 mm polycarbonate strip on top/diagonal edges) produced 100 percent containment without tearing of the plastic inner layer, and with 103 mm (4.5") of deflection. When impacted at the upper rear corner location, this same glazing (with urethane top/diagonal edges) produced 100 percent containment without tearing of the plastic inner layer, and with 154 mm (6.1") of deflection.

- When impacted at the center window location, the polycarbonate glazing (with urethane top/diagonal edges) produced 92 to 100 percent containment without glazing fracture, and with 173 mm (6.8") of deflection. When impacted at the upper rear corner location, this same glazing (with urethane top/diagonal edges) produced 100 percent containment without glazing fracture, and with 175 mm (6.9") of deflection.

- When impacted at the center impact location, the non-HPR trilaminate produced 100 percent glazing containment, but the headform completely penetrated the plastic inner layer. Maximum dynamic deflection was 187 mm (7.4").

- The center window impact location presented a somewhat greater challenge for retention performance than the upper rear corner location. For tests on comparable glazing systems, penetration resistance and glazing containment were the same or better, and maximum dynamic deflections were essentially the same or lower in the corner impacts as compared to the center window impacts.

- The maximum deflection did not necessarily relate to glazing containment or penetration resistance. Therefore, it is likely that to fully evaluate the ejection resistance capability of a glazing system, its performance must be judged based on penetration resistance, glazing containment, and maximum dynamic deflection.

Free-motion headform (FMH) tests were performed for the purpose of assessing the head injury causing potential of advanced side glazing systems, as compared to current tempered glass side windows. The advanced glazings tested were the same as those tested for retention - bilaminate, non-HPR trilaminate, HPR trilaminate, and polycarbonate. The urethane encapsulation was used on all edges (T-edge for vertical edges). The door window frames were also modified as for the retention tests - C-channel on vertical edges, 38 mm deep U-channel on top and diagonal edges, with an additional 25 mm reinforcement at the transition point. For comparison, standard tempered glass windows from three vehicle models were also tested - Honda Civic, Dodge Caravan, and Chevrolet C/K Pickup. Based on the results of these FMH impacts, the following observations were made:

- A critical factor in determining the head injury causing potential of a glazing system may be the glazing's resistance to fracture. For a given glazing and impact configuration, the HIC response was higher if the glass did not fracture. The HIC responses were from about 1½ to four times lower in tests which produced glazing fracture as compared to those that did not.

- The advanced glazings tested did not necessarily produce higher HIC responses than the standard tempered glass side windows. For impacts at 24 kmph, and for cases without glazing fracture, impacts to the Civic tempered window produced HICs of essentially the same level as impacts to the polycarbonate window. Only impacts to the bilaminate window produced slightly higher HICs, if the glazing did not fracture. When tested at 29 kmph (18 mph), the bilaminate fractured, resulting in no increased HIC over the 24 kmph impacts. The tempered window did not always fracture in the 29 kmph impacts, and when it did not, the HICs produced were higher than those produced in the 29 kmph impacts into the polycarbonate (which did not fracture).

- Impacts to the upper rear corner of the window were less likely to produce glazing fracture than impacts to the center. Three of the six glazings tested at the center location (24 kmph) fractured in all tests, while only one glazing fractured in all tests to the upper rear corner location (multiple tests were performed at both locations on each glazing). In cases where the upper corner and center location impacts produced the same fracture result, the upper corner HICs were usually substantially lower.

- Repeatability of the FMH test procedure was good, but the repeatability of the glazing systems was not. Identical impacts frequently produced different fracture results, which generally resulted in large differences in the HIC responses. Since impact speeds were consistent, it was felt that this variation was due largely to the glazing systems and not the procedure. For repeated tests which produced the same fracture results, and which produced HICs of at least 200, the average coefficient of variation (C.V.) was 7.7 percent. For those with average HICs of at least 150, the C.V. was 12.0 percent.

A series of HYGE sled tests was conducted to assess the potential for neck injury due to occupant contact with the advanced side glazing systems, as compared to standard tempered glass windows. A SID/H-III dummy was used and upper neck loads and moments were measured. Two dummy positions were used. In the first, the dummy was leaned 26E toward the glazing, such that the head struck the glazing first. In the second, the dummy was raised so that the head and shoulder struck the glazing simultaneously. The same advanced glazings, encapsulations, and door window frame modifications used in the FMH tests were used in this series. A standard tempered side window and door from a Chevrolet C/K Pickup were also used. Based on the results of the 24 kmph tests, the following observations were made:

- The repeatability of the lateral shear loads, axial loads, and moments about the occipital condyle was generally not good. The variation in pairs of tests averaged ±21.0 percent for the shear loads, ±16.3 percent for the axial loads, and ±15.1 percent for the moments. In each case, the response from the tempered glass impacts were the least repeatable, with variations of ±64.0 percent, ±46.5 percent, and ±30.0 percent for the shear loads, axial loads, and moments. While the glazing systems were certainly a source of this variability, the test procedure itself had a number of variables which could have contributed.

- Impacts into standard tempered glass resulted in lower shear loads and moments than those into the advanced glazings. In each case, and despite the variability, the lowest responses measured were from the tempered glass impacts.

- Due to the high variability, no comparison could be made between the tempered glass and advanced glazings impacts for axial loads. The lowest axial load measured was from one of the tempered glass impacts, while the repeat test produced the second highest axial load.

- The test configuration in which the head and shoulder struck the glazing simultaneously produced lower loads and moments than that in which the head struck first.

Potential safety benefits from advanced glazing are dependent on the safety belt use rate. This report analyzes benefits at four different belt use levels. At the baseline 66.2 percent belt use rate, the advanced glazing could prevent 501 to 1,253 fatalities, 199 to 498 serious (MAIS 3-5) injuries, and 11 to 27 moderate (MAIS 2) injuries. Even if belt use were to increase by 15 percentage points to 81.2 percent, the advanced glazing has the potential to prevent 333 to 833 fatalities, 150 to 377 serious (MAIS 3-5) injuries, and 0 to 2 moderate (MAIS 2) injuries. The advanced glazing could increase the number of minor (MAIS 1) injuries, but the benefits from reduced fatalities and serious injuries would greatly exceed any minor disbenefits. The benefits estimates assume that the advanced glazing systems prevent ejection for 20 to 51 percent of all ejected occupants.

While much of the research on advanced glazing systems has been completed, there are still a few areas in which additional work is planned. These are as follows:

- The retention test needs to be evaluated to see if it is suitable for use in conjunction with other ejection countermeasures (e.g., inflatable curtains, side impact head air bags, etc.). If not, a suitable test procedure may need to be developed that can evaluate all potential ejection countermeasures.

- As discussed in a previous chapter, the neck responses were not repeatable, especially for tempered glass impacts. Additional research is planned to further examine this situation.

- The glazing systems were evaluated for their occupant retention potential in 18 kg impacts at 24 kmph (15 mph). Additional tests will be conducted using a lower impact speed, such as 19½ kmph (12 mph) to determine if occupant retention can be achieved with a lower level of modification to the top and diagonal edges of the door window frame.

- The ejection mitigation of the advanced glazing systems was evaluated on undamaged systems. In many real world crashes, the door frame and/or the glazing may be damaged prior to impact by the occupant. Retention tests will be conducted on pre-damaged systems to explore this situation.

- The laceration potential of advanced glazings will be examined.

- Performance criteria, and associated pass/fail limits, must be finalized. These may include some or all of the following: glazing containment, headform penetration, dynamic deflection, FMH response, and neck loading.

- Additional benefit analyses will be performed, which may include the following:

- Further quantification is needed of the changes in benefits due to differences in neck and head loads from advanced glazings, as compared to current tempered glass windows.

- The containment rates of advanced glazing derived from crash tests should be compared to the containment rates derived from hard copy case reviews to refine the benefit estimates.

- Cost data needs to be developed for the proposed door glazing systems.

- Cost benefit ratios need to be examined for different impact loads to determine the most practicable load for crash tests.

- Cost/benefits analyses need to be conducted which include weight analysis and the use of advanced glazings in rear side windows.

- Potential benefits for several other ejection countermeasures should be analyzed to understand the net benefits of advanced glazing.

10.0 REFERENCES

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APPENDIX

PROBLEM DEFINITION

A.1 Problem Definition Summary

Partial or complete occupant ejections through windows were associated with 7,258 fatalities, 22 percent of all light vehicle fatalities in 1996. Of these fatally-injured occupants, 3,970 were completely ejected and 3,288 were partially ejected. In rollover crashes, glazing-related partial or complete ejections accounted for 4,415 fatalities, or 51 percent of the rollover fatalities in 1996. A total of 17,384 people per year were completely ejected through glazing. Sixty-six percent of the non-windshield glazing complete ejections are through the front-side windows. Head injuries were the most frequent injury in ejections.

A.2 General Ejection Statistics

The agency conducted a review of the number of injuries and fatalities associated with ejections from light motor vehicles, and more specifically, through motor vehicle windows (glazing). The 1996 Fatality Analysis Reporting System (FARS) data and the 1992 through 1996 National Automotive Sampling System (NASS) data were used. The FARS database includes a report of each fatal crash in the 50 states and the District of Columbia that occurred on a public access road. The NASS database is based on a detailed sampling of crashes by 24 field research teams reviewing about 6,000 light vehicle crashes a year.

First, all ejection-related fatalities were identified, regardless of the route of ejection. The 1996 FARS indicated 32,326 people were killed as occupants of cars, light trucks, passenger vans, or utility vehicles. Twenty-seven percent of these fatalities were reported to have been ejected from their vehicles; 21 percent were completely ejected and five percent were partially ejected. Partial ejection is defined as having some portion, but not all, of the occupant's body outside the motor vehicle during the crash. The FARS data are shown in Table A.1.

Table A.1 -- Ejection Status for Occupant Fatalities in Light Passenger Vehicles in 1996 FARS

Event	Fatalities	Percentage
Not ejected	23,633	73%
Completely ejected	6,859	21%
Partially ejected	1,715	5%
Unknown whether ejected	119	-
Total	32,326	100%

The more-detailed NASS data indicate the annual average fatality estimate derived from the 1992 to 1996 data was about 23 percent lower than the 1996 FARS. In 1996, the FARS system reported 32,326 people killed, while the average annual number of fatalities estimated in the 1992-1996 NASS data system was 14,949. Estimates from NASS are that 20 percent of occupant fatalities were completely ejected from the vehicle; this is essentially the same as the percentage indicated by FARS (21 percent). However, the NASS data suggest that FARS is unable to identify about half the partial ejections; 11 percent of fatalities were estimated to have been partially ejected based on detailed NASS investigations, compared to only five percent reported in FARS.

NASS data are most useful for showing percentage distributions of subcategories of the crash events. Therefore, in the following analyses and discussions, the total number of fatalities and the number of completely ejected fatalities (estimated after prorating fatalities with unknown ejection status), as identified in the 1996 FARS database, were used as the basis totals, and percentages from the 1992-1996 NASS database were used for distributions of these totals.

The NASS data used for this analysis include glazing-related ejection injuries for motor vehicles with Gross Vehicle Weight Ratings (GVWR) of 4,536 kilograms (10,000 pounds) or less. When adjusted to the 1996 FARS data (for total fatalities and completely ejected fatalities), the NASS data indicate that 33 percent of the fatalities were related to partial or complete ejections through all vehicle openings, for an annual average of 10,573 people in 1996 (Table A.2). For NASS reports of non-fatal serious injuries (Abbreviated Injury Scale (AIS) 3 or greater)[10], the percentages of complete and partial ejections were markedly less; 8 percent of the seriously injured survivors had been completely ejected and 4 percent of the seriously-injured were partially ejected. This may be an indication that when someone is ejected from the vehicle in a crash, there is a high likelihood of death. An estimated 1.2 percent of all occupants of all light vehicles that were in towaway crashes (without regard to injury outcome) were ejected. An estimate of the distribution of ejection-related injuries is listed below.

Table A.2 -- Ejection Status for Involved Occupants
All Portals, in Light Passenger Vehicles,
Annual Average for 1992-1996 NASS, Adjusted to 1996 FARS

Fatalities			
	Cases	**Estimate**	**Percentage**
Not ejected	1,472	21,753	67%
Completely ejected	437	6,884	21%
Partially ejected	247	3,689	11%
Unknown degree	12	distributed	distributed
Unknown if ejected	83	distributed	distributed
Total	2,251	32,326	100%
Seriously Injured			
	Cases	Estimate	Percentage
Not ejected	3,974	77,047	88%
Completely ejected	408	6,609	8%
Partially ejected	176	3,896	4%
Unknown degree	14	distributed	distributed
Unknown if ejected	87	distributed	distributed
Total	4,659	87,553	100%
All Occupants			
	Cases	Estimate	Percentage
Not ejected	49,569	4,535,987	98.8%
Completely ejected	1,594	34,634	0.8%
Partially ejected	782	20,927	0.5%
Unknown degree	62	distributed	distributed
Unknown if ejected	852	distributed	distributed
Total	52,859	4,591,548	100.0%

An estimated 55,561 partial and complete ejections from light motor vehicles occurred in 1996, based on the average of the 1992 through 1996 NASS fatalities, weighted to the 1996 FARS data.

A.3 Fatalities And Injuries, Related to Glazing Ejections

In total, there was an estimated 7,258 fatalities and 7,810 serious injuries attributed to partial or complete ejection through glazing, based on an average of the 1992 through 1996 NASS with fatalities weighted to the 1996 FARS data.

Table A.3 shows a breakdown of the injury severity, by partial or complete ejection. For the purpose of this analysis, serious injuries were defined as including AIS 3 through AIS 5.

Table A.3 Injury Severity, by Ejection Type Through Glazing
Annual Average for 1992-1996 NASS, Adjusted to 1996 FARS

	Fatality	Serious injury
Complete eject	3,970	4,001
Partial eject	3,288	3,809
Total	7,258	7,810

Table A.3 illustrates that both partial and complete ejections present a safety problem; moreover, the ratio of serious injuries to fatalities is higher for partial ejections than for complete ejections.

The partial or complete ejections through light vehicle windows were associated with 22 percent of all light vehicle fatalities. Additionally, these ejection paths were associated with 9 percent of all serious injuries in 1996. As examined in Winniki,[7] the fatality rates for ejected occupants is much higher than that for non-ejected occupants.

A.4 Glazing Ejection Routes

For the 34,634 complete ejections annually, 17,384 people (50 percent) were ejected through windows (see Table A.4). The most common window ejection routes were the right and left front side windows, comprising 28 percent of all complete ejections. The left and right side front windows constituted 66 percent of the non-windshield glazing complete ejections. The HPR windshields, that were designed to mitigate ejection, still accounted for 8 percent of the complete ejections. Glazing was the portal for 89 percent of partial ejections. This included 21 percent who were partially ejected through the windshield and 50 percent who were partially ejected through a front side window.

Table A.4 -- Ejection Route for Occupants Ejected from Light Passenger Vehicles, Annual Average for 1992-1996 (NASS), Adjusted to 1996 FARS

	Complete Ejection			Partial Ejection		
	Cases	**Estimate**	**Percent**	**Cases**	**Estimate**	**Percent**
Windshield	96	2,682	8	137	4,462	21
Front Windows	428	9,639	28	416	10,489	50
Back Windows	68	1,595	5	58	2,097	10
Backlight	106	2,582	7	32	1,368	7
Roof Window	27	790	2	8	182	1
Other Glazing	7	97	0	2	21	0
Unknown Glazing	2	distributed		0	distributed	
Not Glazing	612	17,250	50	77	2,308	11
Unknown Route	248	distributed		52	distributed	
Subtotal-Glazing	734	17,384	50	653	18,618	89
Totals	1,594	34,634	100	782	20,927	100

The majority of the 10,573 partial and complete ejection fatalities per year were through glazing. On average, 7,258 people per year were killed involving various forms of glazing ejections; 3,970 people per year were completely ejected through glazing and died, and 3,288 people annually were partially ejected through glazing and died. Of these, 1,958 of the complete ejection fatalities and 2,638 of the partial ejection fatalities, totaling 4,596 lives, were attributable to the left and right front side windows.

In Table A.4, two percent of the partial and complete ejections were attributable to roof glazing. But in 1996, 11 percent of all light vehicles had roof glazing. If every light vehicle had roof glazing, the number of ejections could increase dramatically. For example, there were 790 + 182 = 972 partial and complete ejections through roof glazing. If this were expanded to every light motor vehicle, there would theoretically be almost 9,000 roof glazing ejections per year. This points out that roof openings are highly susceptible to ejections because of the direct ejection path for the driver and right front passenger.

A.5 Rollover Versus Non-rollover Crashes

As indicated previously, this research supports the agency's efforts to mitigate rollover crashes, injuries and fatalities. From the 1992 through 1996 NASS data, with fatalities weighted up to the 1996 FARS data, of the 4,591,548 occupants per year involved in towaway crashes, 332,182 occupants were involved in rollover crashes. Of these, there were 8,638 rollover-related fatalities, from all sources. (The remaining 23,688 fatalities in 1996 were attributed to planar (side, front or rear) crashes.) Of these rollover fatalities, 4,415 were due to complete or partial ejection through glazing (See Table A.5).

Table A.5 -- Fatal Glazing Ejections
Annual Average for 1992-1996 NASS, Adjusted to 1996 FARS

	Rollover	Planar	Total
Complete Ejection	3,071	899	3,970
Partial Ejection	1,344	1,944	3,288
Total	4,415	2,843	7,258

As noted in Table A.5, ejections were not unique to rollover. There were 2,843 complete and partial ejection fatalities in planar (non-rollover) crashes. Thus, 7,258 people were killed in crashes involving partial or complete ejections through glazing in 1996. Sixty-one percent of the glazing ejection fatalities were related to vehicle rollover and 39 percent were due to non-rollover, planar crashes. As noted in Figure A-1 and Table A.4, approximately 1.6 times as many people were killed in rollover complete ejections through glazing as were killed in non-rollover partial ejections through glazing.

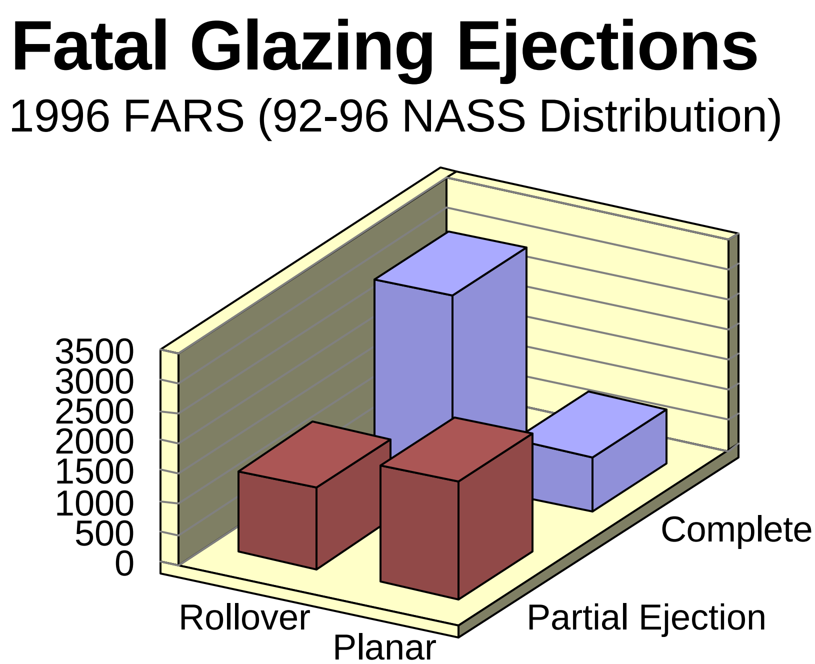

Figure A.1

A.6 Vehicle Type

An analysis was conducted of ejections by vehicle type. There were an average of 55,000 partial and complete ejections per year, as of 1996. About 36,000 partial and complete ejections per year were through glazing. Table A.6 identifies the rate of ejections by vehicle type.

Table A.6 Glazing Ejections by Vehicle Type.
Annual Average for 1992-1996 NASS, Adjusted to 1996 FARS

	Partial Eject	Complete Eject	All Ejections	All crashes	Occupant Eject Rate*
passenger car	12,665	9,793	22,458	3,493,421	6
utility vehicle	1,733	1,591	3,324	237,284	14
vans	734	1,513	2,247	311,680	7
pickups	3,415	4,420	7,835	534,212	14
other	70	69	139	13,914	10
unknown type	0	0	0	1,036	-
total	18,618	17,384	36,002	4,591,548	8

*Ejection rate per 1,000 occupants involved in towaway crashes, by vehicle type.

A.7 INJURIES BY BODY REGIONS

For complete and partial ejections, the greatest number of injuries from all vehicle contact sources was to the head. For complete ejections, head injuries accounted for 65 percent of the injuries. The next most common injury site was the arms, accounting for 18 percent, then torso, legs, and finally the neck. Neck injuries were only 3 percent of the injuries.

The windshield with its penetration resistant qualities, accounted for about half of the head injuries, even though only 8 percent of the complete ejections were through the windshield. Also, the windshield was implicated slightly more often in neck injuries, four percent versus three percent, among all ejected occupants. It is not clear whether this is a manifestation of the penetration resistance of the glazing or the kinematics of an ejection through the windshield. Tempered glass windows, which shattered during the initial stages of the crash, did not cause a significant number of head injuries.
For partial ejections, head injuries constituted 73 percent of the injuries (even for the tempered windows). Neck injuries accounted for an additional 6 percent of these injuries.

A.8 Belt Use Versus Ejection

Previously, the agency showed that virtually all ejected people were unbelted. In one analysis[11] the agency determined the belt use of ejected drivers, using the 1989 FARS data. That study indicated 98 percent of the completely-ejected drivers and right front passengers were unbelted.

In order to determine the affect of increased safety belt use on the reduction of occupant ejections, the two sets of data were compared. As shown in Figure A.2, increased safety belt use has not caused a concurrent decrease in ejected, fatally-injured occupants*. The agency has observed this phenomenon for many years. This problem continues to be addressed by NHTSA as part of its efforts to increase safety belt use.

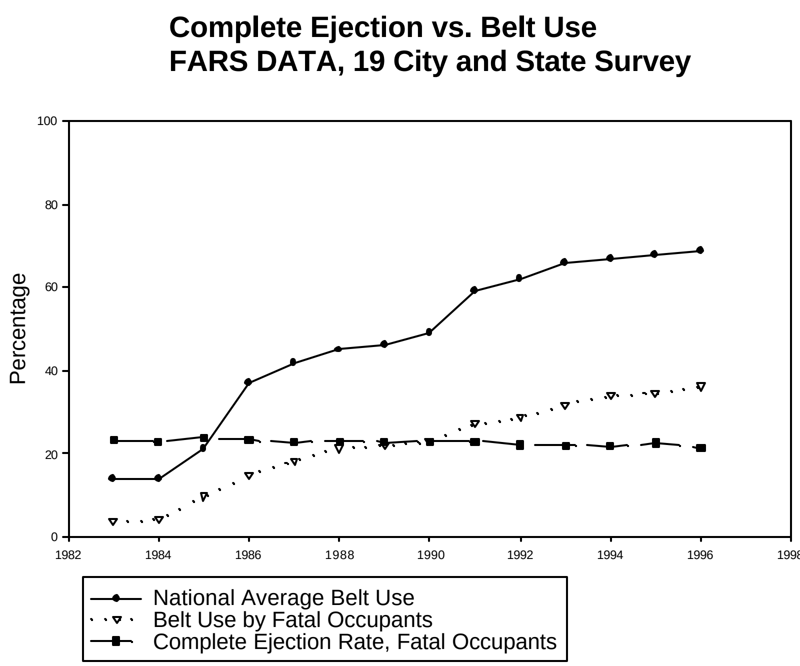

Figure A.2

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*National safety belt use derived from the "19-City Surveys" and current state-reported data. Belt use as reported for fatal occupants, and complete ejection of fatal occupants derived from the Fatal Analysis Reporting System.